EPIDEMIOLOGY OF INJURY IN OLYMPIC SPORTS

EDITED BY DENNIS J. CAINE, PETER A. HARMER AND MELISSA A. SCHIFF

THE ENCYCLOPAEDIA OF SPORTS MEDICINE
AN IOC MEDICAL COMMISSION PUBLICATION

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Foreword

Throughout periods of conditioning and training by athletes and during actual competition, the potential for injury exists as a threat to successful performance. The study of injury mechanisms and the prevention of injuries rely on a comprehensive knowledge base of injury statistics for each particular sport and sports event.

For each Olympic sport and event, the injury statistics have been studied and analyzed by the coeditors and contributing authors of this volume in terms of types of injuries, time and location, risk factors, and inciting conditions. With the overall goal of decreasing the incidence of injuries for athletes in the future, careful consideration has been given to the issues of the prevention of these injuries and the presentation of guidelines for future research.

This volume of the Encyclopaedia of Sports Medicine makes an important contribution to the total understanding of Olympic sports and it is this understanding that exists as the major objective of the Encyclopaedia series. Professors Caine, Harmer, and Schiff, together with all of the contributing authors, are to be congratulated on the quality of the comprehensive coverage that they have provided regarding the epidemiology of sport injuries. We welcome this important addition to the Encyclopaedia of Sports Medicine series.

Dr Jacques Rogge
IOC President

Preface

DENNIS J. CAINE,[1] PETER A. HARMER[2] AND MELISSA A. SCHIFF[3]

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In this age of highly specialized training and intense competition, injuries are common and may sometimes prevent top performers from competing in national and international competitions. Younger athletes who aspire to Olympic participation may also find progress towards top-level competition compromised as a result of injury. Sport injuries may also significantly impact quality of life. There is epidemiological evidence that level of physical fitness is a significant predictor of all-cause mortality, morbidity, and disease-specific morbidity and that physical activity patterns track from early to later life. Injury or incomplete recovery from injury affects the ability to participate in those sport and recreational activities that would be beneficial to health. Injuries may also contribute to the development of osteoarthritis. There is a significant public health cost associated with these injuries, the future development of osteoarthritis, and other diseases associated with decreased levels of physical activity.

We wish to congratulate the Medical Commission of the International Olympic Committee (IOC) on their decision to dedicate an entire encyclopedia volume to the topic of *Epidemiology of Injury in Olympic Sports*. This choice no doubt reflects the growing importance of injury prevention and protecting the health of athletes to support the IOC mission. The purpose of *Epidemiology of Injury in Olympic Sports* is to comprehensively review what is known about the distribution and determinants of injury and injury rates as reported in the literature, and further to evaluate the current research on injury prevention strategies and suggest directions for further research. This book provides a state-of-the-art account of the epidemiology of injury across a broad spectrum of Olympic sports. All sports and events within sports, where there were a sufficient number of studies published to warrant a chapter, are included in this book.

Epidemiology of Injury in Olympic Sports is subdivided into four parts: Summer Sports, Winter Sports, Paralympic Sports, and Injury Prevention and Further Research. Whereas we have included as many summer and winter sports as possible in the first two parts, only one part covering all paralympic sports has been presented, given the paucity of epidemiological studies in these events.

A common, uniform strategy and evidence-based approach to organizing and interpreting the literature is used in this book and applied across all sport-specific chapters, each with the same basic headings so that the reader can easily find common information across chapters:

- Introduction
- Who is affected by injury?
- Where does injury occur?
- When does injury occur?
- What is the outcome?

- What are the risk factors?
- What are the inciting events?
- Injury prevention
- Further research

Each chapter is amply illustrated with tables to make it easy to examine injury factors between studies within a sport and between sports. Most significantly, this book has limited the discussion of risk factors and preventive measures to those which have actually been scientifically tested.

The information in this book will benefit physicians, physical therapists, athletic trainers, sport scientists, sports governing bodies, coaches, parents and reference librarians. Physicians, physical therapists and athletic trainers will find *Epidemiology of Injury in Olympic Sports* helpful in identifying problem areas in which appropriate preventive measures can be tested and ultimately implemented to reduce the incidence and severity of injuries. Some sports scientists as well as healthcare professionals will find the information in this book useful as a basis for continued epidemiological study of injuries in various sports, while others may find it beneficial as a course or reference text. We are optimistic that sports governing bodies and coaches will use this information as an informed basis for the development of injury prevention programs related to such factors as exposure, training techniques, equipment modifications, and rules.

In closing, we would like to thank the authors for their outstanding contributions to this project. The 32 chapters in this book have been written by professionals—including sports medicine physicians, epidemiologists, and exercise scientists—who have expertise in sports injury epidemiology. Researching and writing an epidemiologic overview of the literature in each of the sports areas is a very meticulous and time-consuming endeavor. Increasingly, the professional rewards for chapter contributions are over-shadowed by those received for a successful research grant application or publishing an article in a juried scholarly venue. We therefore view the contributions of the authors to this project as generous donations of their time, effort, and expertise to the IOC specifically and more generally to the field of sports injury epidemiology.

Above all, we would like to thank Dr. Howard Knuttgen and the IOC Medical Commission as well as Cathryn Gates of Wiley-Blackwell for their assistance and patience during this challenging endeavor.

Sport-Specific Chapter Outline

In the Introduction for each chapter, authors were asked to provide the following information: historical background of the sport in the context of the Olympics, relevant background information to establish the importance and need for the review, a well-defined problem statement (what is being reviewed, the population of interest, and for what purpose), and a succinct comment on the methodological limitations of the literature reviewed.

Search methods employed by the authors involved four broad approaches: (1) academic search engines; (2) World Wide Web and Google Scholar; (3) privately owned and government statistical sites; and (4) hand search of references lists (i.e., ancestry approach).

The most commonly used electronic databases were EMBASE, PubMed, and Sport Discus. Other search engines used included: AARP Ageline, Academic Search Premier, Allied and Complementary Medicine (AMED), Biological Abstracts, Cumulative Index to Nursing and Allied Health Literature (CINAHL), Cochrane Central Register of Controlled Trials, Cochrane Database for Systematic Reviews, Cumulative Index for the Physician and Sportsmedicine, Database of Review of Effects (DARE), Health STAR, NHS Economic Evaluation Database, Physical Education Index, ISI Web of Science, Proquest, Proquest Dissertation and Theses, Psych Info, SafetyLit, Social Science Citation Index, Spotlit Scopus, and the Science Citation Index.

Privately owned and government statistical sites used included: AUSPORT, AUSTROM, the Centers for Disease Control and Prevention (CDC), National Center for Health Statistics (NCHS), the National Saftety Council (NSC) Fact Sheets Library, National Collegiate Athletic Association Injury Surveillance System (NCAA ISS), the National Center for Catastrophic Sports Injury

Research, the Royal Society for the Prevention of Accidents (RoSPA) Home and Leisure Accident Surveillance System (HLASS), and the US Consumer Product Safety Commission National Electronic Injury Surveillance System (NEISS).

Sports injury epidemiology is concerned with the who, where, when, what, why, and how of injuries. To address the question of *who* is affected by injury, each author presents a discussion of overall (competition plus practice) rates of injuries and a tabular summary of injury rates by age/participation level, gender, and position played. In many sports, incidence rate data are available (e.g., rate per 1000 hours, snowboard runs, skier days, races, etc.). However, in others, authors had to report clinical incidence (e.g., number of injures divided by the number of injured participants times some *k* value).

Each chapter includes a section on *where* the injury occurred, providing detailed information on anatomic and environmental location. Anatomic information may include a breakdown of injuries by region and/or specific body parts. Environmental location includes whether an injury occurs in practice or competition, indoors or outdoors, by event, or by surface or terrain in which the activity takes place.

The discussion of *when* injuries occur includes injury onset and chronometry. Injury onset addresses information related to the frequency and distribution of acute and overuse injuries. Chronometry may address such time-related factors as time into practice, time of day, and time of season when injury occurred.

Each chapter addresses the question, "*what* is the outcome?", through presentation of data concerning injury type, time loss, clinical outcome, and economic cost. Depending on the research available, the sections on clinical outcome include the following subsections: recurrent injury, catastrophic injury, non-participation, and residual effects of injury.

A discussion of the *why* and *how* of injury is presented in sections on risk factors and inciting events. In the section on risk factors, only data on risk factors that have been tested for correlation or for predictive value are included. Analytical data can point toward factors that contribute to the occurrence of injury. Authors classified risk factors in terms of intrinsic and extrinsic. Intrinsic factors are individual biologic or psychosocial characteristics predisposing an athlete to the outcome of injury, such as previous injury or life stress. Extrinsic risk factors are factors that have an impact on the athlete while he or she is participating in sport, such as training methods or coaching qualifications.

In sports where data were available, authors discussed player-related inciting events leading to the injury situation and which are reported across injuries rather than a description of biomechanical aspects of specific injuries. Player-related aspects typically represent the action or activity leading to the injury (e.g., receiving or delivering a roundhouse kick in taekwondo, collisions in snow-boarding, falls from a horse in equestrian, tackling in soccer, body checking in ice hockey, etc.).

Each chapter includes a section on injury prevention based on research that has attempted to determine the effectiveness of sport-specific preventive measures. This section might be broken down into randomized and non-randomized studies where preventive measures have been tested and/or implemented. In the latter case, for example, the introduction of mandatory full face shield rules among the pediatric ice hockey population has dramatically reduced the frequency of facial and eye injuries.

Finally, authors provide suggestions for further research which arose from their identification of gaps and weaknesses in the epidemiology literature. In these regards they were asked to consider such factors as research questions arising from the epidemiological review, injury definition most appropriate for the sport, study population and sample size considerations, study design, and statistical approaches.

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PART 1

SUMMER SPORTS

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Chapter 1

Aquatics

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Introduction

Although aquatic sports have been part of the Olympic Games since the 1896 Athens Games, the establishment of the International Amateur Swimming Federation (FINA) in 1908 provided much-needed structure to the aquatics competitive program.

Diving evolved from the early "plunging" (1904 St. Louis Games) and "fancy diving" competitions that first appeared over a century ago. Technological advances (i.e., water agitators, springboard metal alloys, video, etc.) have resulted in ostensibly safer facilities but ever more complicated dives. However, few studies exist regarding injuries during training or competition for competitive diving (Anderson & Rubin 1994; Badman & Rechtine 2004).

Competitive swimming has been a constant in the Olympic Games since 1896 for men and since the 1912 Stockholm Olympics for women. Unfortunately, the injury profile for swimming is unclear, as almost all studies on swimming injuries are retrospective and do not account for exposure in determining injury rates.

Synchronized swimming is the most recent addition to the aquatics competition program and has evolved from a mostly esthetic sport in the early 1900s to be included in the Olympic program for the first time in the 1984 Los Angeles Games. Although Weinberg (1986) characterized synchronized swimming as a sport "relatively free of injury," the lack of available data-based evidence makes it difficult to assess the accuracy of this statement.

Water polo was played as "football in the water" starting around 1870 in England; in 1900 it was the first team sport introduced in the Olympic Games. The inclusion of women's water polo at the 2000 Sydney Games indicates that the sport remains popular and has successfully transcended the sex barrier. Few studies have provided a systematic accounting of injuries in water polo, and much remains to be investigated.

This review summarizes existing knowledge and provides guidance for future research regarding the epidemiology of injuries in aquatic sports. In general, multiple methodologic limitations were found in the reviewed literature, including variable injury definitions, differences in the athlete population studied (age, sex, ability, and years of training), small numbers of participants, and problematic data-collection instruments (i.e., recording methods). The majority of the studies were retrospective in design and injury rates were not based on exposure data. This summary of the extant literature on injuries in aquatic sports should be viewed with these limitations in mind.

Who Is Affected by Injury?

A summary of the studies reporting injury rates in aquatic sports is shown in Table 1.1. All of the studies in this review were retrospective, with varying sample sizes (10 to 2496 subjects) and competitive levels, but both sexes were represented. It must also be noted that most of the studies only reported injuries per 100 participants because of the lack of exposure data.

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Table 1.1 Injury rates in aquatic sports.

Study	Study design[a]	Method[b]	No.	Sex	Level[c]	Years of Training (range)	No. of teams	Study Duration	Total No. of injuries	No. of injured athletes	% of athletes injured	No. of injuries per 100 athletes**	Rate (injury / 100 player-hours)	Rate (injury /1000 athlete exposures)
Swimming														
Kennedy & Hawkins 1974b	R	Q	2496		C					261	10.4			
Graham & Bruce 1977[2]	R	Q	78	F	CT			1 year	8			10.2		
Garrick & Requa 1978[2]	R	I/ME	159	77M, 82F	C		6	2 years	8	8	5	5		
Kennedy et al. 1978	R	ME/R	35		NT				43			122		
Richardson et al. 1980	R	I/ME/Q	137	54M, 83F	E, NT	10	3		63	58	42	46		
Zaricznyj et al. 1980[c,d]	R	R	74		C				2	2	2.7	2.7	0.001	
Mutoh et al. 1988[1]	R	Q	19	9M, 10F	E, NT	8.5 ± 2.6			37	19	100	194		
Bak et al. 1989	R	Q	268		C				100	80	30	125	0.09	
Lanese et al. 1990[2]	P	R	57	36M, 21F	CT		2	1 year	29	22	38.5	51	0.12M, 0.08F	
Goldstein et al. 1991	R	I/ME	19	F	E, NT				3	3	15.8	15.8		
McFarland & Wasik 1996[3]	R	ME	68	F	CT				56					2.12
Capaci et al. 2002	R	Q	38	M	C	5.13–6.34			23	23	60.5	60.5		
Diving														
Krejkova et al. 1981	R	ME	40			1 to 30			33	33	82.5	82.5		

Rubin 1983[2]	R	Q	38	14M, 24F	E					32	84			
Mutoh et al. 1988[1]	R	Q	10	5M, 5F	E, NT	8 ± 3.1			30	10	100	300		
Anderson et al. 1993a[1,3]	R	ME/I	14	6F, 8M	E	14.8F, 14.4M			19	4F, 2M	67F, 25M	135		0.00004**
Anderson & Rubin 1994[2]	R	Q	37	16M, 21F	E					34	92			
Rubin et al. 1994[2]	R	Q/ME	20	10F, 10M	NT	11.8–12.7			35	8F, 9M	80F, 90M	175		
Baranto et al. 2006[1]	R	ME	18	14F, 6M	E				89	16	89	494		
Synchronized Swimming														
Mutoh et al. 1988[1]	R	Q	24	F	E, NT	7.9 ± 2.1			31	19	79	163		
Kirkley 1991[2]	R	Q	85	F	AG,E		9		51	38	45	134**		
Water Polo														
Biener & Keller 1985	R	Q	147	M	C,E		35		189	73	50	128**	0.93**	
Mutoh et al. 1988[1]	R	Q	13	M	E, NT				27	12	92.3	225		
McLain & Reynolds 1989[3]	R	ME	54	36M, 16F	C	8.5 ± 1.5	2	1 year		2M, 0F	5M, 0F			
Jerolimov & Jagger 1997	R	Q	102	M	C, E		8		329			322		
Annett et al. 2000[3]	R	ME	77	M	E, NT			13 years	278			361**		1.16**
Junge et al. 2006[3])	R	R	156**	M	NT				17	17	10.9	10.8**	6.3	2.8**

[1] pain; [2] medical problem that resulted in time loss, [3] any musculoskeletal complaint
[a] R=Retrospective
[b]: I=Interview; Q=Questionnaire; ME=Medical Exam; R=school/accident report
* Data for organized school teams only, ** Calculated from data
M= Males, F=Females
[c]: C=Competitive, AG= Age Group, NT=National Team/Olympic/World Championships, E=Elite, M=Masters, CT=College team

Diving

Only Mizel et al. (1993) examined injuries in groups other than elite or national team level, and all but Mizel et al. (1993) and Anderson et al. (1993b) indicated clinical injury rates in divers between 80% and 100%. Rubin and Anderson (1996) presented data from Zimmerman (1993), who reported 8.8 injuries per 1,000 training hours, and Gabriel (1992), who studied medical insurance carrier reports of injury over 3 years that indicated 6.5 injuries per 100 participants per year for divers.

Swimming

As shown in Table 1.1, available studies indicated a prevalence of overall injuries ranging from 2.7 to 194 injuries per 100 athletes. Only McFarland and Wasik (1996) reported an exposure-based injury rate (2.12 injuries per 1,000 athlete exposures) for "any musculoskeletal problem reported to medical personnel."

Water Polo

Few studies have systematically examined injuries in water polo, and all are retrospective, with sample sizes ranging from 13 to 156, mostly using male participants. Injuries are primarily reported as prevalence, ranging from 5% to 92%.

Where Does Injury Occur?

Anatomical Location

A summary of the available data on percent distribution of injuries by anatomical location for aquatic sports is presented in Tables 1.2 (diving, synchronized swimming, water polo) and 1.3 (swimming). Some studies also reported rates by specific body location, which will be discussed below.

Diving

In divers, most injuries involve the low back (18.8% to 89%), neck (10.3% to 65.7%), and shoulder (20.7% to 85%). Rubin (1983) cited an unpublished study by Mangine (1981) on 66 divers, 89% of whom experienced back pain on multiple occasions. He then surveyed 37 elite divers (ages, 11 to 26 years), 61% of whom reported upper-extremity injuries, 61% back injuries, and 40% neck problems. Anderson, Gerard and Zlatkin (1993a) noted that 42% of elite divers experience neck pain. Others have also noted frequent injuries (24% to 29%) at the hand and wrist (Anderson et al. 1993b, Mutoh, Takamoto & Miyashita 1988). Mizel et al. (1993) found that 45% of injuries in a sample of 120 competitive divers were to the ankle and foot.

Swimming

A review of Table 1.3 reveals that the most frequent injury location for swimmers is the shoulder (12% to 87%), followed by the knee and the lower back. A multitude of investigators have examined the effects of swimming on shoulder injuries alone (i.e., Dominguez 1978b, Richardson et al. 1980, McMaster et al. 1989, McMaster & Troup 1993, Burchfield et al. 1994, Stocker et al. 1995, Bak & Fauno 1997, Johnson et al. 2003) with similar results. Dominguez (1978b) reported that 22% of swimmers 11 to 12 years of age and 65% of swimmers 13 to 18 years of age reported shoulder pain.

The knee is the second most common injury site among swimmers, with prevalences ranging from 6% to 28%, although Hahn and Foldspang (1998) described 62.3% in 53 Danish swimmers. According to Vizsolyi et al. (1987), breaststrokers experienced a higher prevalence of knee-related problems than non-breaststrokers (73% and 48%, respectively). Rovere and Nichols (1985) added that 47% of swimmers cited weekly knee pain, with 75% having knee pain at least three times per season.

Capaci et al. (2002) concluded that 33.3% of butterfliers and 22.2% of breaststroke swimmers experienced lower back injuries. Mutoh (1978) found a 37% rate of injuries for butterfliers. Drori et al. (1996) reported a 50% rate of injuries for butterfliers and 47% for breaststrokers.

In a study of 45 cases of insertion tendonitis in swimmers, Merino and Llobet (1978) conveyed that 73% were shoulder-related (51% freestyle, 42% backstroke, and 6% butterfly), 13.5% were in the groin (17% each in breaststroke and backstroke and 66% in the butterfly), and 13.5% involved the knee (66% in breaststroke and 34% in the butterfly).

Table 1.2 Comparison of injury onset.

	Diving		Synchronized Swimming		Water Polo				
Study	Mutoh et al. 1988	Anderson et al. 1993b*	Mutoh et al. 1988	Kirkley 1991	Biener & Keller 1985	Mutoh et al. 1988	Jerolimov & Jagger 1997	Annett et al. 2000	Junge et al. 2006
No. of athletes	10	113M, 138F	24	85	147	13	102	77	156
Total No. of injuries	**30**	**143M, 227F**	**31**	**51**	**189**	**27**	**329**	**278**	**17**
Head/face	3	10.6M, 11F			39		96.4	15.5	53
Neck	10.3	14.7M, 14F	6.5			7.4		4.7	
Upper Extremity		10.5M, 9.2F			1				
Shoulder	20.7			41	4	18.5	0.9	24.1	6
Elbow			3	8	3	4	0.3	11.5	6
Forearm									
Wrist/hand/finger	24.1		25.8		28	8	1.2	19.7	18
Lower Extremity		18.2M, 22.9F			8				
Hip/groin					10			7.1	
Knee	7.1	14.7M, 13.2F	12.9	33		25.9	0.3	3.6	
Ankle	7.1		3						
Foot					2			1.7	6
Toe							0.3		
Trunk/Low back	27.6	31.5M, 29.5F	45.2	8	5	37	0.3	7.9	11
Other/Not specified			3	10			0.3	4.2	

[a] Sex is reported when known.

* Calculated from data.

Table 1.3 Percentage distribution of injuries in swimming by anatomical location.[a]

Study	Kennedy & Hawkins 1974b	Graham & Bruce 1977	Kennedy et al. 1978	Zaricznyj et al. 1980	Mutoh et al. 1988	Bak et al. 1989	McMaster et al. 1989	McFarland & Wasik 1996	Richardson 1999	Capaci et al. 2002
No. of athletes	2496	78	35		19	268	473	68	886	38
Total no. of injuries	**261**	**8**	**43**	**51**	**37**		**239**	**56**	**886**	**23**
Head/face				47				7	26	
Neck		12.5		10	3	2	13			
Upper Extremity		12.5								
Shoulder	31	12.5	37		31.4	38	87	55	3	56.5
Elbow				2		4				
Forearm				2						
Wrist/hand/finger				10	3	2		4	18	
Lower Extremity								5	32	
Hip/groin										
Knee	26.8	25	28	6	20	18		11	5	13
Ankle				6	5.7					
Foot	32.5		19	13		8				
Toe										
Trunk/Low back		12.5		4	37.1	22		18	3	30.4
Other/Not specified	9.7	25	16			3				13

[a] When totals are greater than 100%, multiple injuries are involved.

Water Polo

Water polo players suffer chronic shoulder injuries at varying rates (3% to 38%) (Rollins et al. 1985, Webster et al. 2009). Knee injuries (3.6% to 25.9%), acute head and orofacial injuries (15.5% to 53%), and hand injuries (8% to 29%) are also common. Jerolimov and Jagger (1997) estimated 3.1 orofacial injuries per player. The prevalence of shoulder injury detailed by Colville and Markman (1999) approached 80%, and this remains the most current estimate. Biener and Keller (1985) stated that 39% of all injuries were to the head and face and that 28% involved the wrist, hand, and fingers.

Environmental Location

Diving

Rubin and Anderson (1996) cited a study by Gabriel (1992) in which 60% of injuries in athletes 13 to 18 years of age and 43.3% of injuries in divers 19 to 30 years of age occurred during practice. They also included work by Zimmerman (1993), in which 92% of the 37 recorded injuries took place during training. Mizel et al. (1993) reported that springboard diving accounted for 55% of foot and ankle injuries, dry-land training (i.e., gymnastics, trampoline) for 13%, platform diving for 4%, and other events (such as exiting the pool) for 28% of injuries in a sample of divers. In terms of the timing of injury within a dive from the springboard, 12% were related to the approach, 35% to the hurdle, and 53% to the press phase just prior to take off.

Swimming

The available data suggested that most swimming injuries occur during training. For example, Garrick and Requa (1978) reported that 100% of injuries in male and 57% in female high-school swimmers occurred during practice; 4% of female swimmers were injured during competition. McMaster et al. (1989) noted that 5.1% of males and 14.6% of females aged 13 to 14 years found weight training painful. McFarland and Wasik (1996) detailed similar injury rates from swimming and cross training for swimming (1.05 and 1.07 injuries per 1,000 athlete exposures, respectively). Weight-bearing activities accounted for the majority of the cross-training injuries (running, 47%; running steps, 13%; pulling sleds, 9%), and weight training caused 24%. Richardson (1999) found that 42% of injuries occurred in the water, 22% on the deck, 7% outside the pool, 6% in the locker room, 5% on the bleachers, 3% on the starting blocks, 2% each for hallway and gym, 1% on stairs; 10% were from unspecified causes, although these figures involved 91% athletes and 9% nonathletes or guests. The author also noted that 54% of injuries occurred during competition, 31% during practice, 8% at warm-up, 2% on dry land, and 5% other.

Synchronized Swimming

Most injuries affecting synchronized swimmers can be attributed to activities in the water, although Kirkley (1991) reported that 27% of shoulder injuries and 12% of knee injuries occurred during weight training.

Water Polo

An analysis of injuries in team sports during the 2004 Olympic Games indicated that male water polo players suffered 30 injuries per 1,000 matches, 63 injuries per 1,000 player-hours, or 2.8 injuries per 1000 athlete exposures (Junge et al. 2006). Biener and Keller (1985) reported injury rates differed between games (4.16 injuries per 100 games), practices or friendly games (1.64 injuries per 100 games), and practices (2.7 per 1,000 hours of practice). The authors also reported that goaltenders suffered 43% of injuries during training (mostly from shots from other players), as opposed to 22% of field players. There are no reports of water polo injuries taking place in areas around the pool or in other training facilities.

When Does Injury Occur?

Injury Onset

Most injuries in aquatic sports are chronic in nature, and are associated with highly repetitive motions (i.e., arm cycles in swimming or eggbeater kicks in water polo). However, onset may also vary by anatomical location and the mechanism of injury. For example, acute shoulder injuries are common in divers during impact with the water (i.e., Anderson &

Rubin 1994, Rubin et al. 1993), whereas chronic shoulder injuries are common in swimmers (see discussion below).

Diving

Rubin and Anderson (1996) cited a study by Zimmerman (1993) in which 62.2% of injuries were acute and 37.8% classified as “overuse.” Baranto et al. (2006) reported that the median age for the first episode of back pain in divers was 15 years old.

Swimming

Stulberg et al. (1980) reported that 82% of swimmers experienced knee pain within 3 years of beginning the breaststroke. Rovere and Nichols (1985) suggested that knee pain in breaststroke may involve a short-term problem characterized by overuse and a long-term progressive chronic condition.

Water Polo

Annett et al. (2000) classified 73.4% of water polo injuries as acute, 26.6% as due to overuse, and 20.5% as chronic in nature (lasting 6 weeks or longer) (Figure 1.1).

Chronometry

Diving

Baranto et al. (2006) studied 18 elite divers (average age, 17 years) using magnetic resonance imaging and clinical examination and reported that 67% suffered abnormalities in the thoracolumbar spine, with the first incident of back pain coinciding with a growth period (median, 15 years), and 94% of the injuries occurring when the athletes were 14 to 17 years of age. The authors also estimated that the probability of experiencing back pain within 1 year was 45% after divers reached 13 years of age.

Swimming

Ciullo and Stevens (1989) cited data from Troup et al. (1987), who found that most injury referrals started around the age of 18, when swimmers had been training for approximately 10 years and are entering a more intense training and competition schedule. Of elite swimmers who experienced shoulder pain during swimming, 83% indicated that the pain was more prevalent during the early and middle section of the swimming season (Richardson et al. 1980). The authors also noted an increase in injuries as swimmers move from competitive (27%; males, 38%; females, 23%) to elite (52%; males, 47%; females, 57%) to championship caliber (57%; males, 50%; females, 68%). Dominguez (1978b) studied three age groups (≤8 years old, 9–12 years old, and 13–18 years old) and reported a 2% prevalence of pain in 9-to-12-year-old swimmers, and 65% in 13-to-18-year-olds. Richardson et al. (1980) found that 47% to 68% of elite swimmers experienced pain, as opposed to 23% to 38% of younger, nonelite swimmers.

Figure 1.1 In water polo, contact with the opponent is often a cause of acute shoulder injury. © IOC /Tsutomu KISHIMOTO.

Stulberg et al. (1980) and Hahn and Foldspang (1998) reported 82% of swimmers had knee pain within 3 to 4 years of beginning breaststroke.

Synchronized Swimming

Kirkley (1991) stated that 64% of all injuries occurred during the conditioning part of the training season (speed swimming, synchronized swimming, weight training, and flexibility conditioning) and 36% occurred during the routine preparation phase (choreography, compulsory figures, and practice of routine).

Water Polo

Junge et al. (2006) found that 41% more injuries occurred in the second half of games as compared with the first half. However, the timing of injury was not reported for 35% of recorded injuries.

What Is the Outcome?

Injury Type

This review included only reports that addressed injuries specific to aquatic sports. Illnesses in aquatic athletes such as mononucleosis or anemia were excluded. For specific conditions such as otitis externa (swimmer's ear), which is often attributed to infections from *Pseudomonas aeruginosa*, readers are referred to several reviews (i.e., Calderon & Mood 1982, Gerrard 2004, Nichols 1999, Wang et al. 2005).

Diving

Since the first reports of injuries in competitive divers (Groher 1973), several studies have discussed different types of injury outcomes such as damage to soft tissue or ligaments or both, intervertebral disk protrusions and degeneration, and stress fractures (Carter 1994, Kimball et al. 1985, Rubin 1983). Mizel et al. (1993) reported that in 55 injuries suffered by 41 divers (age $\geq$ 18 years) 33% were ankle sprains, 31% fractures (all lower-extremity), 9% Achilles tendon contusions, 7% midfoot strains, 5% cuticle injuries, and 15% miscellaneous injuries. Anderson et al. (1993b) noted that fractures were the most common injury for both male and female junior Olympic divers (44.2% and 52.9%, respectively). Anderson et al. (1993a) reported that specific diagnoses included asymmetry in muscle development (57% of divers), cervical-motion restriction (15–50%), positive Spurling's test (50%), facet-joint tenderness (79%), spasm of the trapezius (79%), and bone spurs (57%; 50% of females and 62.5% of males). Rubin et al. (1993) reported that 80% of a group of 20 elite divers exhibited shoulder instability, inflammation, and acromioclavicular-joint injury, including acute subluxations and dislocations, and traction tendinitis.

In an early report, Rossi (1978) noted that 25 of 30 divers (83.3%) exhibited isthmic modifications, with 63.3% exhibiting spondylolysis and 15.8% spondylolisthesis. Rossi and Dragoni (2001) reported that divers had the highest prevalence of spondylolysis (23 of 57 athletes, 40.35%) of 37 sports studied.

Swimming

Of age group swimmers who reported shoulder pain, Dominguez (1978a) identified 39% with coracoacromial ligament tenderness and another 10.9% with Class 3 symptoms (disabling pain during and after the activity to the degree that it affects performance). Mutoh (1978) reported that 22% of butterfliers suffered from spondylolysis and intervertebral-disk narrowing. McMaster et al. (1989) found that 4% of age-group swimmers experienced shoulder dislocation or subluxation, and 13.5% of males and 12% of females also experienced nonspecific neck pain. A variety of studies have established that breaststrokers experience knee injury in significant numbers (54–100%), including medial and lateral collateral ligament sprains, medial femoral condyle contusion, and synovitis of the medial compartment (Hahn & Foldspang 1998, Hawkins & Kennedy 1974, Kennedy & Hawkins 1974a, Keskinen et al. 1980, Rodeo 1999, Rovere & Nichols 1985, Stulberg et al. 1980, Vizsolyi et al. 1987). Finally, Soler and Calderon (2000) found that spondylolysis developed in 10.2% of swimmers, although a third were asymptomatic.

Synchronized Swimming

Kirkley (1991) conducted a cross-sectional study that showed that 71% of swimmers with shoulder injury were diagnosed with rotator cuff tendinitis, 24% of swimmers presented with patellofemoral pain syndrome (24%), and 100% of lumbar spine injuries were muscle strains.

Water Polo

Junge et al. (2006) recorded foot fracture (1 case), tympanic membrane rupture (2), eye contusion (1), shoulder dislocation (1) and sternal fracture (1) during the 2004 Athens Olympic Games water polo competition. In a retrospective study of 77 elite players, Annett et al. (2000) found that frequent injury types included finger and thumb sprains (8.3% of total injuries) and supraspinatus tendinitis (7.9%), eye injuries (6.1%), and tympanic-membrane trauma (6.1%). Jerolimov and Jagger (1997) concluded that 96.4% of water polo injuries were orofacial, with cuts to the lips accounting for 48%, followed by the tongue (12.8%) and cheek (9.1%). Finally, Merino and Llobet (1978) reported shoulder and elbow insertion tendinitis in water polo players.

Time Loss

Diving

Anderson and Rubin (1994) indicated that cervical injuries required 43% of elite divers (67% of females, 25% of males) to miss at least 1 week of training. Similarly, Rubin et al. (1993) reported that 16 of 20 national team divers missed at least 1 week of practice at some point because of shoulder injury associated with diving. Conversely, Rubin and Anderson (1996) cited Zimmerman (1993), where 31 of 40 divers (77.5%) who reported an injury missed 4 hours of practice or less, and 90% returned to practice within 2 weeks.

Swimming

Dominguez (1978b) reported that at least 10% of age-group swimmers (13–18 years) missed practice or swimming meets. Richardson et al. (1980) indicated that 81% of swimmers with shoulder pain diminished daily training and 40% had to stop training for a short period. Garrick and Requa (1978) found 71% of female high-school swimmers missed 5 days or more. Hip abductor injury caused 9.2% of breaststrokers and 6.3% of individual medley swimmers to miss competition (an average of 2.2 and 2.6 missed competitions, respectively), but 42.7% of breaststrokers missed an average of 11.5 practices, and 21.5% of nonbreaststrokers missed an average of 6.9 practices (Grote et al. 2004). Hahn and Foldspang (1998) also noted that 24.5% of swimmers missed time because of breaststroke-related knee injury. McFarland and Wasik (1996) stated that only 4 of 56 injuries in their study resulted in $\geqslant$21 days away from participation in practice. Lanese et al. (1990) reported 241.5 disability days for males and 63.5 for females (1.43 and 0.62 disability days per 100 person-hours, respectively) in their 1-year study of a collegiate swim team. Merino and Llobet (1978) concluded that tendinitis does not adversely affect swimmers, as 84% returned to full performance in 1 month or less, with only 3% not being able to return to the sport.

Synchronized Swimming

Kirkley (1991) reported an average of 28 hours of practice time and 6% of synchronized swimming competitions lost due to injury, for an average of 1 week without training over the course of one full competitive season.

Water Polo

McLain and Reynolds (1998) noted that injuries in male high-school water polo players resulted in the athletes missing an average of 5 days of participation. Junge et al. (2006) reported that time away from participation because of injury ranged from 2 days (eye contusion) to $\geq$ 30 days for a fractured sternum for participants in the 2004 Olympic Games, with an incidence for time-loss injuries of 8.7 per 1,000 matches (19 injuries per 1,000 player-hours). Annett et al. (2000) noted that no acute water polo injury resulted in more than 6 weeks away from participation in their 13-year study of elite male players. Finally, Biener and Keller (1985) found that in a sample of 147 players, 48% did not miss practice or playing time because of injury, whereas 24% missed unspecified time, 10% missed one practice, and 18% did not report.

Clinical Outcome

Diving

Lebwohl (1996) reported two fatalities on record worldwide due to impact of the head with the platform during a complicated reverse somersault dive. Rubin (1983) referenced a study by Groher (1973) on divers who trained for more than 5 years, in which 33% experienced "unusual rigid attitude in their lumbar spine," 55% demonstrated restricted flexion, and 40% had limited extension. Of these, arthritis of the spinous processes developed in 50% , arthritis of the vertebral joints in 55%, and spondylolysis in 20%. Krejcova et al. (1981) indicated that 67% of divers exhibited reduced mobility of the spine, 47% had rotation blockade, 23% had reduced mobility of the lumbosacral region, and 47.5% scoliosis, but the authors did not connect these outcomes to specific prior or current injuries. Baranto et al. (2006) reported that in a 5-year follow-up after an initial examination, 12 of 17 divers (median age, 17 years at baseline) experienced a total of 89 spinal abnormalities and 3 quit competing altogether.

Krejcova et al. (1981) also found, from vestibular and optokinetic examinations, evidence of vestibular disease in 75% of all divers (27.5% peripheral and 47.5% central) and electroencephalogram examination revealed abnormal patterns in 57.5% of divers.

Swimming

A review of the National Center for Catastrophic Sport Injury Research (NCCSI) website indicated five indirect (systemic failure as a result of exertion or complication secondary to nonfatal injury) and eight direct (caused by participation in the sport) catastrophic injuries in high-school female swimmers and one indirect fatality in a female college swimmer from 1982 through 2007 (National Center for Catastrophic Sport Injury Research 2008). Richardson (1999) indicated that among 886 accidents reported during USA Swimming–sanctioned competitions, 78% were minor (i.e., minor contusions, falls around the pool, small lacerations, etc.), 19% were major (undefined), and 3% were fractures. Dominguez (1978a) presented a case series of three swimmers with debilitating chronic shoulder pain who underwent successful coracoacromial ligament resection, resulting in pain-free participation in swimming. McFarland and Wasik (1996) noted low rates of surgery for swimming and swimming cross-training injuries (4% and 5%, respectively).

Synchronized Swimming

Mutoh et al. (1988) reported that in their study, 19 of 24 participants (79%) experienced chronic pain; 73.7% of them required medical treatment.

Water Polo

The NCCSI records indicated a total of four indirect high-school fatalities in water polo and one at the college level from 1992 to 2007 (National Center for Catastrophic Sport Injury Research 2008). Jerolimov and Jagger (1997) found that 33% of water polo injuries required medical treatment, and Annett et al. (2000) reported that 20.5% of acute and overuse water polo injuries became chronic. Biener and Keller (1985) noted that 36% of injuries required no treatment, 36% were self-treated and 22% required a visit to a physician or hospital, mostly for dental injuries. Hame et al. (2004) described a total of 20 fractures (16 male and 4 female) in collegiate Division I water polo players during a review of fractures spanning 14 years.

Economic Cost

This literature review did not identify any studies that analyzed the economic costs associated with injuries in aquatic sports.

What Are the Risk Factors?

Intrinsic Factors

Swimming

Gender differences: Sallis et al. (2001) concluded that female swimmers at Pomona College sustained more injuries than their male peers (47.08 vs. 12.37 injuries per 100 participant years, $P < 0.001$). Specifically, differences in rates (injuries per 100 participant-years) existed in the shoulder (21.05 vs. 6.55, $P < 0.01$), knee (5.85 vs. 1.45, $P < 0.01$), back and neck (8.19 vs. 1.45, $P < 0.01$), and hip (2.34 vs. 0.00, $P < 0.01$).

Age differences: Vizsolyi et al. (1987) concluded that swimmers who were older and trained more had a greater incidence of injury than younger, less experienced swimmers ($P < 0.001$), but the authors did not distinguish between age and training as causes for injury. Bak et al. (1989) indicated that medley swimmers had a significantly higher proportion of injuries (54%) as compared with swimmers specializing in a single stroke (freestyle, 41%; backstroke, 32%; breaststroke, 32%; and butterfly, 37%).

Water Polo

To date, no study has conclusively connected risk factors to specific injuries in water polo, although Sallis et al. (2001) reported that female collegiate players experienced significantly more injuries than their male peers (18.38% vs. 7.10%, $P < 0.001$), with shoulder injury rates also significantly higher (8.09% vs. 3.40%, $P < 0.01$). Hame et al. (2004) concluded that male water polo players had a significantly greater rate of fractures than female players (4.1 vs.1.3 injuries per 100 athlete-years of participation).

Extrinsic Factors

Some studies have attributed injuries to specific equipment, or lack thereof. For example, Burchfield et al. (1994) argued that the introduction of hand paddles and pull buoys correlated temporally with the onset of, and increases in, the prevalence of shoulder pain in age-group swimmers (33 of 56 swimmers aged 13 to 18 years, $P < 0.001$). In water polo, Jerolimov and Jagger (2007) concluded that the use of mouth guards would result in fewer orofacial injuries during water polo. However, there is a complete void of research describing the role of extrinsic factors in the development of injuries in aquatic sports.

What Are the Inciting Events?

Diving

Few researchers have presented information as to the inciting events of injuries in diving. According to several authors (i.e., Anderson & Rubin 1994, Kimball et al. 1985, Rubin 1983), the acrobatic nature of diving and the impact with the water are the inciting events associated with the anatomical distribution of injuries in diving.

Swimming

Kennedy and Hawkins (1974a) and Capaci et al. (2002) identified the whipkick during breaststroke as the cause of all knee injuries in swimmers. Stulberg et al. (1980) concluded that all 23 swimmers in their study experienced pain during the final thrust of the whipkick. Based on a 48% prevalence of knee pain in nonbreaststrokers, Vizsolyi et al. (1987) concluded that the breaststroke kick can generate pain even when used on a limited basis during training. Rovere and Nichols (1985) reported that the most notable event associated with the onset of knee pain in breaststrokers was an increase in breaststroke training distance (81%), followed by weight lifting (19%), and running and inadequate warm-up (16% each). Pain in the lower extremity has also been linked to the use of the kickboard in 9% of females and 11% of males aged 13 to14 years (McMaster et al. 1989).

Capaci et al. (2002) indicated that 11 of 23 swimmers experienced pain during and after workouts ($P < 0.0001$). Richardson et al. (1980) reported that 81% of swimmers stated that hand paddles exacerbated their shoulder pain. In contrast, Stocker et al. (1995) found no association between paddle use and shoulder pain, but 50% of the swimmers associated pain with increased distance or intensity or both. McMaster et al. (1989) concluded that although 77% of females and 88% of males used paddles in training, only 16.8% of females and 20.7% of males experienced pain during swimming. However, shoulder pain was positively correlated ($P < 0.05$) with stretching, weight training, kickboard use, and sleep (in females). Burchfield et al. (1994) indicated that 49 of 56 swimmers who incorporated weight lifting in their training experienced shoulder pain.

Synchronized Swimming

In the single study that provided data on the activities that resulted in injury during synchronized swimming, Kirkley (1991) reported that the precipitating events for shoulder injury were weight training (29%), butterfly swimming (24%), and sculling (43%). For knee injury, the causes were eggbeater motion (70%), synchronized swimming in general (18%), and weight training (12%).

Water Polo

Junge et al. (2006) found that all injuries reported during the 2004 Olympics were due to contact with another player. Biener and Keller (1985) indicated that 65% of injuries in field players were caused by contact with an opponent (48% accidental and 17% intentional), whereas the ball caused 13% of injuries and players' own mistakes caused 19% of injuries. In contrast, 74% of injuries sustained by goalkeepers were due to contact with the ball, with only 14% resulting from accidental contact with another player. Annett et al. (2000) stated that kicks were the cause of chest and abdominal injuries in water polo (9 of 334 injuries overall).

Injury Prevention

Few well-designed studies on the impact of injury-prevention strategies in aquatic sports exist. For example, Rovere and Nichols (1985) reported that reducing breaststroke training was the most effective treatment for knee-pain reduction in breaststrokers (84%). Dominguez (1978b) stated that a weight-lifting program diminished shoulder pain in 8.5% of male swimmers ages 13 to 18. Ciullo (1986) cited his earlier study, in which the initiation of a stretching program decreased shoulder impingement in swimmers training over 12,000 yards per day from 80% to approximately 14%. However, none of these were controlled studies. Overall, this review revealed a dearth of prospective studies that examined injury-prevention protocols in any aquatic sports in a scientifically valid way.

Further Research

One consistent pattern that emerges from this review was the difficulty of accurately describing injury rates, causes of injury, or strategies that can reduce the risk of injury, because of the lack of valid studies. The small number of participants, lack of controls, and diversity of data-acquisition methods (i.e., medical insurance reports vs. reports to a coach), classification (i.e., chronic vs. acute, sprain vs. strain, etc.) and treatment of injuries, make identification of injury characteristics (severity, type, etc.) difficult. Above all, this review underscores the need for standardized injury surveillance systems in all aquatic sports without which a comprehensive understanding of injury risks and resolutions is not possible. For example, in examining sex as a risk factor, Troup et al. (1987) identified differences in prevalence of pain between male and female swimmers (70% vs. 65%, respectively) but Richardson et al. (1980) reported the opposite effects of sex and shoulder injuries among elite and national team swimmers (47–50% for males and 57–68% for females). Lanese et al. (1990), however, found no differences between the sexes.

In a separate example in water polo injuries, the single study that included longitudinal data (13 years) did not provide insights as to injury rates across that time span (Annett et al. 2000). Similarly, Jerolimov and Jagger (1997) found that pivot players experienced a higher rate of orofacial injuries (5.5 injuries per player) than defensive/attacking players (3.5 injuries per player), attacking players (3.1 injuries per player), and goalkeepers (0.6 injury per player), but these data were not evaluated for significance. There is a clear need for well-designed prospective cohort studies to address these basic issues.

Questions that remain unanswered for each of the aquatic sports include the following: What training practices result in injuries? What can be done to minimize or eliminate these injuries? What is the relationship between growth rates and injury rates? When is it safe to introduce certain elements, such as weight training or paddles into the training schedule, and how should these be introduced? What are the long-term effects of injuries in aquatic sports? These examples of specific areas for future research in all the aquatic sports will enable coaches, medical personnel, researchers, and athletes to ensure safe and productive training and competition experiences for all.

References

Anderson, S.J., Gerard, E.S. & Zlatkin, M. (1993a) Cervical spine problems in competitive divers, In: *United States Diving 1993 Sport Science Seminar* (R.M. Malina & Gabriel, J.L., eds.), U.S. Diving Publications, Indianapolis, 144.

Anderson, S.J., O'Brien, R., Gabriel, J.L., Heusner, W.W., Malina, R.M., Geithner, C.A., Golden, D. & Shea, J. (1993b)

Sport, medical and injury background of junior Olympic divers. In: *United States Diving 1993 Sport Science Seminar* (R.M. Malina & Gabriel, J.L., eds.). U.S. Diving Publications, Indianapolis, p. 41–49.

Anderson, S.J. & Rubin, B.D. (1994) Evaluation and treatment of injuries in competitive divers. In: *Sports Medicine and Rehabilitation: A Sport-Specific Approach* (Buschsbacher, B. & Braddom, R.L., eds.), Hanley & Belfus, Philadelphia, pp. 95–106.

Annett, P., Fricker, P. & McDonald, W. (2000) Injuries to elite male waterpolo players over a 13 year period. *New Zealand Journal of Sports Medicine* **28**, 78–83.

Badman, B.L. & Rechtine, G.R. (2004) Spinal injury considerations in the competitive diver: a case report and review of the literature *The Spine Journal* **4**, 584–590.

Bak, K., Bue, P. & Olsson, G. (1989) Injury patterns in Danish competitive swimming. *Ugeskrift for Laeger* **151**, 2982–2984.

Bak, K. & Fauno, P. (1997) Clinical findings in competitive swimmers with shoulder pain. *American Journal of Sports Medicine* **25**, 254.

Baranto, A., Hellström, M., Nyman, R., Lundin, O. & Swärd, L. (2006) Back pain and degenerative abnormalities in the spine of young elite divers. *Knee Surgery, Sports Traumatology, Arthroscopy* **14**, 907–914.

Biener, K. & Keller, W. (1985) Sport accidents during water polo matches. *Deutsche Zeitschrift fuer Sportmedizin* **36**, 276–281.

Burchfield, D., Cofield, S. & Cofield, R. (1994) Shoulder pain in competitive, age-group swimmers. *Medicine and Sport Science* **39**, 218–225.

Calderon, R. & Mood, E.W. (1982) A epidemiological assessment of water quality and "swimmer's ear." *Archives of Environmental Health* **37**, 300–305.

Capaci, K., Ozcaldiran, B. & Durmaz, B. (2002) Musculoskeletal pain in elite competitive male swimmers. *The Pain Clinic* **14**, 229–234.

Carter, R.L. (1994) Competitive diving. In: *Sports Injuries: Mechanism, Prevention, Treatment.* (Fu, F.H. & Stone, D.A., eds.), Williams & Wilkins, Baltimore, pp. 261–281.

Ciullo, J.V. (1986) Swimmer's shoulder. *Clinics in Sports Medicine* **5**, 115–137.

Ciullo, J.V. & Stevens, G.G. (1989) The prevention and treatment of injuries to the shoulder in swimming. *Sports Medicine* **7**, 182–204.

Colville, J.M. & Markman, B.S. (1999) Competitive water polo: upper extremity injuries. *Clinics in Sports Medicine* **18**, 305–312.

Dominguez, R.H. (1978a) Coracoacromial ligament resection for severe swimmer's shoulder. In: *Swimming Medicine IV* (Eriksson B. & Furberg B., eds.), University Park Press, Baltimore, pp. 110–114.

Dominguez, R.H. (1978b) Shoulder pain in age group swimmers In: *Swimming Medicine IV* (B. Eriksson & B. Furberg, eds.), University Park Press, Baltimore, pp. 105–109.

Drori, A., Mann, G. & Constantini, N. (1996) Low back pain in swimmers: is the prevalence increasing? *The Twelfth International Jerusalem Symposium on Sports Injuries*, Book of Abstracts, Tel Aviv, 75.

Gabriel, J. (1992) *USA Diving Injury Surveillance Data*. USA Diving, Indianapolis.

Garrick, J.G. & Requa, R.K. (1978) Injuries in high school sports. *Pediatrics* **61**, 465.

Gerrard, D.F. (2004) Medical issues related to swimming. In: *Swimming*, 2nd ed. (Stager, J. & Tanner, D., eds.), Blackwell Science, Malden, pp. 115–127.

Goldstein, J.D., Berger, P.E., Windler, G.E. & Jackson, D.W. (1991) Spine injuries in gymnasts and swimmers: an epidemiologic investigation.*American Journal of Sports Medicine* **19**, 463–468.

Graham, G.P. & Bruce, P.J. (1977) Survey of intercollegiate athletic injuries to women. *Research Quarterly* **48,** 217–220.

Groher, W. (1973) Rueckenschmerzen und roentgenologische Veraenderungen der Wirbelsaeule bei Kunst- und Turnspringern (in German). [Low back pain in divers.] *British Journal of Sports Medicine* **7**, 100–102.

Grote, K., Lincoln, T.L. & Gamble, J.G. (2004) Hip adductor injury in competitive swimmers. *American Journal of Sports Medicine* **32**, 104–108.

Hahn, T. & Foldspang, A. (1998) Prevalent knee pain and sport. *Scandinavian Journal of Social Medicine* **26**, 44–52.

Hame, S.L., Lafemina, J.M., McAllister, D.R., Schaadt, G.W. & Dorey, F.J. (2004) Fractures in the collegiate athlete. *American Journal of Sports Medicine* **32**, 446–451.

Hawkins, R.J. & Kennedy, J.C. (1974) Breast stroker's knee. *Physician & Sportsmedicine* **2**, 33–35.

Jerolimov, V. & Jagger, R.G. (1997) Orofacial injuries in water polo. *Kinesiology* **29**, 32–34.

Johnson, J.N., Gauvin, J. & Fredericson, M. (2003) Swimming biomechanics and injury prevention, *Physician & Sportsmedicine* **31**, 41–46.

Junge, A., Langevoort, G., Pipe, A., Peytavin, A., Wong, F., Mountjoy, M., Beltrami, G., Terrell, R., Holzgraefe, M., Charles, R. & Dvorak, J. (2006) Injuries in team sport tournaments during the 2004 Olympic Games. *American Journal of Sports Medicine* **34**, 565–576.

Kennedy, J.C. & Hawkins, R.J. (1974a) Breaststroker's knee. *Physician & Sportsmedicine* **2**, 33–35.

Kennedy, J.C. & Hawkins, R.J. (1974b) Swimmer's shoulder. *Physician & Sportsmedicine* **2**, 34–38.

Kennedy, J.C., Hawkins, R. & Krissoff, W.B. (1978) Orthopaedic manifestations of swimming. *American Journal of Sports Medicine* **6**, 309–322.

Keskinen, K., Eriksson, E. & Komi, P. (1980) Breaststroke swimmer's knee: a biomechanical and arthroscopic study. *American Journal of Sports Medicine* **8**, 228–231.

Kimball, R.J., Carter, R.L. & Schneider, R.C. (1985) Competitive diving injuries. In: *Sports Injuries: Mechanisms, Prevention, and Treatment*. (Schneider, R.C., Kennedy, J.C. Plant, M.L., et al., eds.), Williams and Wilkins, Baltimore, pp. 192–211.

Kirkley, A. (1991) Musculoskeletal injuries in elite synchronized swimmers. *Clinical Journal of Sport Medicine* **1**, 183–187.

Krejcova, H., Krejci, L., Jirout, J., Stracarova, B. & Rezek, P. (1981) Vestibular and neurological disorders in diving competitors. *Annals of the New York Academy of Sciences* **374**, 839–845.

Lanese, R.R., Strauss, R.H., Leizman, D.J. & Rotondi, M. (1990) Injury and disability in matched men's and women's intercollegiate sports. *American Journal of Public Health* **80**, 1459–1462.

Lebwohl, N.H. (1996) Diving. In: *The Spine in Sport.* (Watkins, R.G. & Williams, L., eds.), Mosby, St. Louis, pp. 391–396.

Mangine, R. (1981) Back injuries in diving: a preliminary report. In: *Proceedings United States Sports Diving Seminar* (Golden, D., ed.), U.S. Diving Publications, Indianapolis: pp. 123–130.

McFarland, E.G. & Wasik, M. (1996) Injuries in female collegiate swimmers due to swimming and cross training. *Clinical Journal of Sport Medicine* **6**, 178–182.

McLain, L.G. & Reynolds, S. (1989) Sports injuries in a high school. *Pediatrics* **84**, 446.

McMaster, W.C. & Troup, J. (1993) A survey of interfering shoulder pain in United States competitive swimmers. *American Journal of Sports Medicine* **21**, 67.

McMaster, W.C., Troup, J.P. & Arredondo, S. (1989) Incidence of shoulder problems in developing elite swimmers. *Journal of Swimming Research* **5**, 11–16.

Merino, J.A. & Llobet, M. (1978) Insertion tendonitis among swimmers. In: *Swimming Medicine IV* (Eriksson B. & Furberg B., eds.), University Park Press, Baltimore, pp. 101–104.

Mizel, M.S., Rubin, B., Decker, E., Trepman, E., O'Brien, R. & LeFace, K. (1993) Prevention of foot and ankle injuries in competitive divers. In: *United States Diving 1993 Sport Science Seminar* (R.M. Malina & Gabriel, J.L., eds.), U.S. Diving Publications, Indianapolis, pp. 129–131.

Mutoh, Y. (1978) Low back pain in butterfliers. In: *Swimming Medicine IV* (B. Eriksson & B. Furberg, eds.), University Park Press, Baltimore, pp. 115–123.

Mutoh, Y., Takamoto, M. & Miyashita, M. (1988) Chronic injures of elite competitive swimmers divers, waterpolo players, and synchronized swimmers. In: *Swimming science V: [proceedings of the]/Vth international symposium of biomechanics and medicine in swimming.* Human Kinetics, Champaign, IL, pp. 333–337.

National Center for Catastrophic Sport Injury Research (2008)*National Center for Catastrophic Sport Injury Research*. URL http://www.unc.edu/depts/nccsi/ [accessed on July 30, 2008].

Nichols, A.W. (1999) Nonorthopedic problems in the aquatic athlete. *Clinics in Sports Medicine*, **18**, 395–411.

Richardson, A.B. (1999) Injuries in competitive swimming. *Clinics in Sports Medicine* **18**, 287–291.

Richardson, A.B., Jobe, F.W. & Collins, H.R. (1980) The shoulder in competitive swimming. *American Journal of Sports Medicine* **8**, 159–163.

Rodeo, S.A. (1999) Knee pain in competitive swimming. *Clinics in Sports Medicine* **18**, 379–387.

Rollins, J., Puffer, J.C., Whiting, W.C., Gregor, R.J. & Finerman, G.A. (1985) Water polo injuries to the upper extremity. In: *Injuries to the throwing arm.* (Zarins, B., Andrews, J.R. & Carson, W.G., eds.). W.B. Saunders, Philadelphia, 311–317.

Rossi, F. (1978) Spondylolysis, spondylolisthesis and sport. *Journal of Sports Medicine & Physical Fitness* **18**, 317–340.

Rossi, F. & Dragoni, S. (2001) The prevalence of spondylolysis and spondylolisthesis in symptomatic elite athletes: radiographic findings. *Radiography* **7**, 37–42.

Rovere, G.D. & Nichols, A.W. (1985) Frequency, associated factors, and treatment of breaststroker's knee in competitive swimmers. *American Journal of Sports Medicine* **13**, 99–104.

Rubin, B.D. (1983) Orthopaedic aspects of competitive diving injuries. In: *The Proceedings of the United States Diving Sports Sciences Seminar* (Golden, D., ed.), Karger, Basel, p. 65.

Rubin, B.D. & Anderson, S.J. (1996) Diving. In: *Epidemiology of Sports Injuries* (Caine, D.J., Caine, C. & Lindner, K., eds.), Human Kinetics, Champaign, IL, pp. 176–185.

Rubin, B.D., Chandler, T.J., Anderson, D.G. & Kibler, W.B. (1993) A physiological and shoulder injury profile of elite divers. In: *United States Diving 1993 Sport Science Seminar* (R.M. Malina & Gabriel, J.L., eds.), U.S. Diving Publications, Indianapolis, pp. 158–164.

Sallis, R.E., Jones, K., Sunshine, S., Smith, G. & Simon, L. (2001) Comparing sports injuries in men and women. *International Journal of Sports Medicine* **22**, 420–423.

Soler, T. & Calderon, C. (2000) The prevalence of spondylolysis in the Spanish elite athlete. *American Journal of Sports Medicine* **28**, 57–62.

Stocker, D., Pink, M. & Jobe, F.W. (1995) Comparison of shoulder injury in collegiate- and master's-level swimmers. *Clinical Journal of Sport Medicine* **5**, 4–8.

Stulberg, S.D., Shulman, K., Stuart, S. & Culp, P. (1980) Breaststroker's knee: pathology, etiology, and treatment. *American Journal of Sports Medicine* **8**, 164–171.

Troup, J.P., Forbes, T., Heppes, L., Arredondo, S. & Dude, L. (1987) Training methodology: an analysis of elite and developmental swimmers performance profiles. In: *Report from U.S. Swimming Sports Medicine Program*. US Swimming Press, Colorado Springs.

Vizsolyi, P., Taunton, J., Robertson, G., Filsinger, L., Shannon, H.S., Whittingham, D. & Gleave, M. (1987) Breaststroker's knee: an analysis of epidemiological and biomechanical factors. *American Journal of Sports Medicine* **15**, 63–71.

Wang, M.C., Liu, C.Y., Shiao, A.S. & Wang, T. (2005) Ear problems in swimmers. *Journal of the Chinese Medical Association: JCMA* **68**, 347–352.

Webster, M.J., Morris, M.E. & Galna, B. (2009) Shoulder pain in water polo: a systematic review of the literature. *Journal of Science and Medicine in Sport*, **12**, 3–11.

Weinberg, S.K. (1986) Medical aspects of synchronized swimming. *Clinics in Sports Medicine* **5**, 159–167.

Zaricznyj, B., Shattuck, J.M., Mast, T.A., Robertson, R.V. & D'Elia, G. (1980) Sports-related injuries in school-aged children. *American Journal of Sports Medicine* **8**, 318–324.

Zimmerman, W. (1993) *Registration of injuries in springboard and platform diving in The Netherlands.* Medical School Thesis, University of Leiden, The Netherlands.

Chapter 2

Archery

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Introduction

Archery was introduced as an official sport in the 1900 Paris Olympic Games and included in the 1904, 1908, and 1920 Olympics. Women were allowed to participate in the 1904 and 1908 Games.

Because of a lack of uniform rules, archery was dropped from the Olympic Games program after 1920. It reemerged in the 1972 Munich Olympic Games, and has been on the program since.

Today, archery is popular as a competitive sport, with a 14.8% increase in the number of participants in the United States from 2000 to 2006. In 2006, approximately 7.5 million individuals (⩾6 years of age; males, 72.3%, females, 27.7%) participated in archery at least once (Sporting Goods Manufacturers Association 2007), with 529,000 archers practicing frequently (⩾ 52 events/year).

Archery is governed by the International Archery Federation, which consists of member National Governing Bodies, including USA Archery, which supports developmental programs such as the Junior Olympic Archery Development for younger archers and Paralympics organizations for archers with disabilities. Today, archery attracts athletes of both sexes and of all ages with its easy-to-learn but challenging pursuit of mastery.

Until recently, archery has been neglected by the scientific community. The recent rise in popularity has stimulated new but modest medical research on its injury patterns. The purpose of this chapter is to present a comprehensive review of the research literature on injury patterns in archery. These data should communicate to researchers the need for an easily accessible universal data bank for storing information on, studying, and reporting injuries in this increasingly popular sport.

Who Is Affected by Injury?

We located only two articles that reported prevalence data for archery. Ertan and Tuzun (2000) used a questionnaire to poll 88 archers at the 2000 Turkish Archery Championship, half of whom were novice competitors. Although the reported prevalence of injury was high (56.8%), the definition of a reportable injury is unknown. Mann and Littke (1989) also used a retrospective questionnaire to study 21 archers who qualified for the Canadian World Championship team in 1987 and reported 38.1 injuries per 100 participants.

Where Does Injury Occur?

Anatomical Location

Most reported archery injuries are in the upper extremities (Figure 2.1). Injuries are also described in the chest, neck, and back. Table 2.1 compares the percent distribution of injuries by location.

Ertan and Tuzun (2000) identified the most frequently injured body part as the fingers, followed by the shoulder of the drawing arm. Chen et al. (2005) studied 24 elite archers at the Tsoying National Sport Training Center and found the

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Figure 2.1 Most reported archery injuries involve the upper extremities © IOC / Tsutomu KISHIMOTO

shoulder and the wrist to be most commonly injured, with 15 of the 24 archers reporting an injury to each of these areas (62.5%). Renfro and Fleck (1991) reference an archery injury report of musculoskeletal injuries at the Olympic Training Center in Colorado Springs, Colorado, over a 10-month period during which 16 of 33 reported injuries (48.5%) were to the shoulder, while 14 (42.4%) were in the upper back muscles. There was no mention of the remaining 3 injuries.

Data collected from the National Electronic Injury Surveillance System (NEISS; U.S. Consumer Product Safety Commission 2007), which included numerous hunting-related archery injuries, indicated that the most frequent site for injury was the fingers (35.4%), followed by the hand (15.7%). Only 10 (2.7%) of the 370 injuries were reported to affect the shoulder girdle.

Environmental Location

We found no studies that commented on environmental influences and the impact on archery injuries, although NEISS data indicate that the majority of the archery injuries in the general population (48.6%) occurred at home.

We have suggested that archers are more likely to sustain an injury during practice rather than competition, as the majority of an archer's time in the sport is spent practicing. For example, Mann and Littke (1989) noted that, on average, both males and females trained for 11 months per year. However, no studies have examined the distribution of injuries between practice and competition.

When Does Injury Occur?

Injury Onset

There are no data available on the relative frequency or distribution of acute and chronic injuries in archers. Table 2.2 lists published reports on acute and chronic injuries in archery.

Chronometry

There are no published studies examining the influence of time in practice or time of the competitive season on injury occurrence.

What Is the Outcome?

Injury Type

Acute

Case reports and case series in the NEISS indicate a diverse range of acute injury types, including lacerations, fractures, contusions, and acute compression neuropathies (U.S. Consumer Product Safety Commission 2007). However, it is not possible to separate competition archery from hunting injuries

Table 2.1 Percentage comparison of injury location.

	Sorenson (1978)	Fingleton (1987)	Fukuda & Neer (1988)	Mann & Littke (1989)	Whiteside & Andrews (1989)	Shimizu et al. (1990)	Renfro & Fleck (1991)	Rayan (1992)
Injuries	1	13	2	21	1	1	33	7
Head, neck, or chest	100	100				100	42	
Upper Extremities								
Shoulder			100	100			49	
Arm								
Elbow					100			28.6
Forearm								14.3
Wrist								28.6
Hand								14.3
Fingers								14.3
Lower Extremities								
Pelvis								
Thigh								
Knee								
Leg								
Ankle								
Foot								
Toes								
Not Otherwise Specified							9	

Table 2.2 Comparison of injury onset.

Study	Injury Onset	Level of Evidence	Number of Injuries	Number of Participants
Fingleton (1987)	Acute	IV	13	13
Rayan (1992)	Acute	IV	3	5
Vogel & Rayan (2003)	Acute	IV	1	1
Sorenson (1978)	Acute	V	1	1
Fukuda & Neer (1988)	Chronic	IV	2	2
Shimizu et al. (1990)	Chronic	IV	1	1
Rayan (1992)	Chronic	IV	4	5
Naraen et al. (1999)	Chronic	IV	1	1
Whiteside & Andrews (1989)	Chronic	V		
Sicuranza & McCue (1992)	Chronic	V		
Rehak (2001)	Chronic	V		
Ciccotti & Ramani (2003)	Chronic	V		
Dimeff (2003)	Chronic	V		
Safran (2004)	Chronic	V		
Toth et al. (2005)	Chronic	V		
Mann & Littke (1989)	Unknown	III	8	21
Ertan & Tuzun (2000)	Unknown	III	50	88
Renfro & Fleck (1991)	Unknown	V	33	Unknown

Level III = case–control study; Level IV = case series; Level V = expert opinion.

Naraen et al. (1999)	Ertan & Tuzun (2000)	Rehak (2001)	Ciccotti & Ramani (2003)	Dimeff (2003)	Vogel & Rayan (2003)	Safran (2004)	Chen et al. (2005)	Toth et al. (2005)	U.S. Consumer Product Safety Commission (2007)
1	75	1	1	1	1	1	80	4	370
	2.7					100	6.3	25	16.2
	20						18.8		5.9
							6.3		1.4
100	1.3		100				2.5		1.6
	10.7	100		100			0	25	6.2
	12						18.8	25	4.6
	8				100		6.3	25	15.7
	20						0		35.4
							13.8		1.1
							6.3		1.6
							11.3		1.1
	1.3						3.8		2.9
							2.5		0.8
							3.8		3.5
							0		1.4
	24								0.5

in these data. Ertan and Tuzun (2000) reported finger blisters as the most frequent (20%) injury type in 88 competitive archers surveyed, followed by abrasions and contusions to the soft tissue of the bow forearm (10.7%) caused by string touches or "string slap."

Chronic

Chronic injuries occur because of repetitive microtrauma, and are often referred to as "overuse" syndromes. In archery, they present as repetitive concentric and eccentric loading on muscles causing fatigue and tendinitis of the surrounding muscles (Mann & Littke 1989; Whiteside & Andrews 1989; Renfro & Fleck 1991; Ciccotti & Ramani 2003). Archery-related overuse syndromes have also been reported as physeal injuries of immature archers (Naraen et al. 1999). There are also reports of recurrent shoulder instability due to repetitive stresses created by the archer's stance (Fukuda & Neer 1988; Mann & Littke 1989; Renfro & Fleck 1991; Mann 1994). Compression neuropathies are also caused by repetitive compression, traction and friction inflicted on these peripheral nerves (Rayan 1992; Sicuranza & McCue1992; Rehak 2001; Dimeff 2003; Safran 2004; Toth, McNeil & Feasby 2005). Table 2.3 lists specific studies on types of injuries.

Time Loss

There are currently no studies in the published literature on time lost from competition, practice, or work.

Clinical Outcome

Vascular Injuries

Bow hunter's stroke is a term coined by Sorensen (1978) after he described a 39-year-old male with neurologic symptoms from a stroke while practicing archery. Ischemic lesions developed in the vertebrobasilar system from head rotation that caused

Table 2.3 Comparison of injury type.

Diagnosis	Sorenson (1978)	Fingleton (1987)	Fukuda & Neer (1988)	Mann & Littke (1989)	Whiteside & Andrews (1989)	Shimizu et al. (1990)	Renfro & Fleck (1991)	Rayan (1992)	Naraen et al. (1999)	Ertan & Tuzun (2000)	Rehak (2001)	Ciccotti & Ramani (2003)	Dimeff (2003)	Vogel & Rayan (2003)	Safran (2004)	Toth et al. (2005)
Vascular	+															
Nerve Compression																
Digitital nerve								+								+
Median nerve at wrist								+								+
Pronator syndrome								+			+		+			+
Long thoracic nerve						+									+	+
Overuse																
Tendinopathy																
de Quervain disease								+								
Medial epicondylitis								+				+				
Lateral epicondylitis					+											
Rotator cuff			+	+			+			+						
Upper back musculature							+									
Instability																
Shoulder			+													
Fracture																
Coracoid process									+							
Trauma																
Finger Blister										+						
Metacarpal fracture														+		
Forearm contusion								+		+						
Laceration								+								
Penetrating		+														

Table 2.4 Comparison of the level of evidence with purported archery-related risk factors.

Study	Level of Evidence	Number	Purported Risk Factor
Mann & Littke (1989)	III	21	Age, sex
Ertan & Tuzun (2000)	III	88	Training time, experience
Fukuda & Neer (1988)	IV	2	Technique
Shimizu et al. (1990)	IV	1	Technique
Rayan (1992)	IV	5	Technique
Naraen et al. (1999)	IV	1	Training time
Vogel & Rayan (2003)	IV	1	Technique

Level III = case–control study; Level IV = case series; Level V = expert opinion.

stenotic changes in the vertebral artery. Sorensen detailed characteristics of the archer's posture during practice and correlated them with pathology. The author suggested that archers experiencing dizziness or facial tingling while shooting should end practice and seek medical care. Hanakita et al. (1988) have documented the same phenomenon.

Musculotendinous Injuries

Fukuda and Neer (1988) examined shoulder instability among archers and noted posterior instability and recurrent dislocation, possibly due to improper posture and technique (although there is no evidence that this contention is accurate).

Mann and Littke (1989) surveyed 21 elite archers and found that most of their injuries occurred in the drawing-arm rotator cuff, especially among females, in the form of impingement tendinitis of the supraspinatus and long head of the biceps tendons. Renfro and Fleck (1991) reported similar findings.

Whiteside and Andrews (1989) and Frostick et al. (1999) have reported that the repetitive loading of the wrist extensors can produce lateral epicondylitis in archers. Medial elbow tendinopathy has also been described (Whiteside & Andrews 1989; Rayan 1992; Frostick et al. 1999; Ciccotti & Ramani 2003). Rayan (1992) described a patient with de Quervain tendinopathy from misuse of the release mechanism.

Nerve-Compression Injuries

Shimizu et al. (1990) reported the case of a 20-year-old male in whom a winged scapula gradually developed on the side of his drawing arm. This was attributed to traction or compression of the long thoracic nerve during archery practice. Three systematic reviews of peripheral-nerve injuries in sports have identified archery as a potential cause for long thoracic nerve palsy (Dimeff 2003; Safran 2004; Toth et al. 2005).

The median nerve is also at risk during archery. Sicuranza & McCue (1992), Rayan (1992), and Rehak (2001) all described median-nerve compression neuropathy from archery. Rayan (1992) also reported a radial sensory-nerve compression neuropathy from misuse of the release mechanism.

Miscellaneous Injuries

Skeletal injuries have been reported in skeletally immature athletes. Naraen et al. (1999) published a case report of an 11-year-old archer with epiphyseal injury of his coracoid process from overuse. They detailed the patient's symptoms of pain in his nondominant shoulder during archery training.

Rayan (1992) reported on a 38-year-old archer who sustained an open small finger metacarpal fracture of the dominant hand, which occurred when the patient mishandled the bow as he was drawing, allowing the bow to discharge onto his hand.

Economic Cost

To our knowledge, the economic impact of sustaining an archery-related injury in competitive athletes has not been studied.

What Are the Risk Factors?

There are no studies to date that have published analytical data on either intrinsic or extrinsic risk factors. Table 2.4 lists purported risk factors and the level of evidence associated with each article.

Rayan (1992) documented in two case reports injuries resulting from failure to use appropriate protective equipment.

What Are the Inciting Events?

Mann & Littke (1989) indicate that frequent neck symptoms in the form of paracervical and upper torso muscle stiffness and pain are due to the asymmetrical head and neck position and torso/ upper extremity muscle imbalance during firing posture. They noted that poor stance, posture, and firing technique may lead to stress and pathologic changes at the thoracolumbar junction of the lower spine. However, no data are provided to confirm this.

Injury Prevention

Currently, there are no published studies examining the effectiveness of injury-prevention measures in competitive archers.

Further Research

There is a scarcity of evidence-based medicine and epidemiologic data on archery injuries. Issues such as creation of an international surveillance system, standardization of reporting injuries, identification of risk factors, and injury prevention need research development. For example, recommendations on injury prevention, including proper stretching and warm-ups, weight-training, careful selection of bow weights, limits on the number of arrows fired in one session, drawing technique to prevent median-nerve compression, and the impact of non-compliance in using protective equipment have not been examined (Sicuranza & McCue 1992; Naraen et al. 1999; Ertan & Tuzun 2000). Although Mann and Littke (1989) found no correlation with bow weights and related injuries, several studies (Mann & Littke 1989; Rayan 1992; Naraen 1999; Ertan & Tuzun 2000) have reported an association between hours practiced/arrows fired and different injury patterns. For example, Ertan and Tuzan (2000) reported a mean of 12.3 hours training per week (4.4 training sessions of 2.8 hours per day) with an average of 168.5 arrows per session using a mean bow weight of 39.8 lb in a sample of elite Turkish archers. The authors calculated the estimated weekly work of 13.5 tons to be a risk factor for injury, but provide no data to demonstrate an association. In addition, Mann and Littke (1989) studied shoulder injuries among elite athletes and found a significant difference between daily practice hours for males (3.3) and females (2.4), but noted that women manifested more clinical signs of shoulder injuries and reported higher number of prior injuries than males. However, explicit exploration of this proposed relationship is lacking.

Archery deserves better awareness in the literature, and attention should be focused on more research related to the biomechanics and epidemiology of its injuries. Epidemiologic studies are the foundation on which most clinical studies build their infrastructure. The challenge is for future scientists to develop research methods that would recognize, prevent, and treat injuries and, ultimately, improve the well-being of archers and advance the sport of archery.

References

Chen, S.K., Cheng, Y.M., Lin, Y.C., Hong, Y.J., Huang, P.J. & Chou, P.H. (2005) Investigation of management models in elite athlete injuries. *Kaohsiung Journal of Medical Science* **21**, 220–227.

Ciccotti, M.G. & Ramani, M.N. (2003) Medial epicondylitis. *Sports Medicine and Arthroscopy Review* **11**, 57–62.

Dimeff, R.J. (2003) Entrapment neuropathies of the upper extremity. *Current Sports Medicine Reports* **2**, 255–261.

Ertan, H. & Tuzun, M. (2000) *Injury patterns among Turkish archers.* Middle East Technical University, Ankara/Turkey.

Fingleton, L.J. (1987) Arrow wounds to the heart and mediastinum. *British Journal of Surgery* **74**, 126–128.

Frostick, S.P., Mohammad, M. & Ritchie, D.A. (1999) Sport injuries of the elbow. *British Journal of Sports Medicine* **33**, 301–311.

Fukuda, H. & Neer, C.S. (1988) Archer's shoulder: recurrent posterior subluxation and dislocation of the shoulder in two archers. *Orthopedics* **11**, 171–174.

Hanakita, J., Miyake, H., Nagayasu, S., Nishi, S. & Suzuki, T. (1988)

Angiographic examination and surgical treatment of bow hunter's stroke. *Neurosurgery* **23**, 228–232.
Mann, D.L. (1994) Injuries in archery. Sports-Specific Injuries. In: *Clinical Practice of Sports Injury Prevention and Care* (Xxxxx, X., ed.), Blackwell Scientific Publications, Osney, Oxford: pp. 665–675.
Mann, D.L & Littke, N. (1989) Shoulder injuries in archery. *Canadian Journal of Sports Science* **14**, 85–92.
Naraen, A., Giannikas, K.A. & Livesley, P.J. (1999) Overuse epiphyseal injury of the coracoid process as a result of archery. *International Journal of Sports Medicine* **20**, 53–55.
Rayan, G.M. (1992) Archery-related injuries of the hand, forearm, and elbow. *Southern Medical Journal.* **85**, 961–964.
Rehak, D.C. (2001) Pronator syndrome. *Clinics in Sports Medicine* **20**, 531–540.
Renfro, G.J. & Fleck, S.J. (1991) Preventing rotator cuff injury and reaching optimal athletic performance in archery through resistance exercise. *The US Archer* July–Aug, 194–195.
Safran, M.R. (2004) Nerve injury about the shoulder in athletes, part 2. *The American Journal of Sports Medicine* **32**, 1063–1076.
Shimizu, J., Nishiyama, K., Takeda, K., Ichida, T. & Sakuta, K. (1990) A case of long thoracic nerve palsy, with winged scapula, as a result of prolonged exertion on practicing archery. *Clinical Neurology* **30**, 873–876.
Sicuranza, M.J. & McCue, F.C. (1992) Compression neuropathies in the upper extremity of athletes. *Hand Clinics* **8**, 263–273.
Sorensen, B.F. (1978) Bow hunter's stroke. *Neurosurgery* **2**, 259–261.
Sporting Goods Manufacturers Association (2007) *Archery Participation Report 2007.* SGMA, Washington, DC.
Toth, C., McNeil, S. & Feasby, T. (2005) Peripheral nervous system injuries in sport and recreation, a systematic review. *Sports Medicine* **35**, 717–738.
U.S. Consumer Product Safety Commission (2007) National Electronic Injury Surveillance System (NEISS). URL http://www.cpsc.gov/library/neiss.html [accessed on 2007].
Vogel, B.R. & Rayan, G.M. (2003) Metacarpal fracture from archery: a case report. *Journal of Oklahoma Medical Association* **96**, 79–80.
Whiteside, J.A., & Andrews, J.R. (1989) Common elbow problems in the recreational athlete. *The Journal of Musculoskeletal Medicine* **6**, 17–34.

Chapter 3

Athletics

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Introduction

Athletics, also known as track and field, is a group of sport events that involve running, jumping and throwing (Official Olympic games website 2009). The name "athletics" is derived from the Greek word *athlon*, meaning "contest."

Track and field athletics was included in the first modern Olympic Games in 1896, and has been present at every Olympic Games. While the number and type of events have changed over time, the men's program has become fairly standardized since 1932. From the original 46 track and field events, only 24 remain in the current games. Women were first allowed to participate in a few track and field events at the 1928 Olympics (Official Olympic games website 2009). Presently, women compete in 23 events. Thus, the only difference is that men compete in one more race walk (50 km) than women (Official Olympic games website 2009). Currently, track and field athletics can be classified in to four areas: (1) track events, including sprints (100 m, 200 m, 400 m), middle-distance running (800 m, 1500 m) and long-distance running (5000 m, 10,000 m), hurdling (110 m for women, 110 m and 400 m for men), relays (110 m and 4 × 400 m) and 3000-m steeple chase; (2) field events, including long jump, triple jump, high jump, shot put, discus, javelin, and hammer throw, and pole vault; (3) road events (marathon, 10-km race walk for women, 20 km and 50 km race walks for men); and (4) combined events (heptathlon for women, decathlon for men) (Official Olympic games website 2009).

While discontinued as an Olympic sport in 1924, we included cross-country running in our review because (1) few studies have reported on competitive track and field distance running events, (2) many runners who participate in collegiate or interscholastic track and field also participate in cross-country, either competitively or for fall training, (3) although there is a difference in surface type, the biomechanical and training mechanisms for running are similar for the two sports, and (4) cross-country continues to be popular at multiple competitive levels.

While participation in competitive track and field and cross-country may include benefits such as medals, scholarships, and improved cardiovascular health, it also carries the risk of musculoskeletal injury. With the large number of participants and diverse events, the sport of track and field poses special problems for medical professionals and sports injury researchers who monitor, treat, and recommend preventive measures to minimize injuries. Runners strike the ground approximately 800 to 1500 times per mile with forces of 1.5 to 5 times body weight experienced by the foot, and that force is transferred up the kinetic chain (Cavanaugh & Lafortune 1980; Subtonick 1985; Hreljac 2004). Because middle and distance (and cross-country) running events require more repetitious movements

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during training and competition, these runners may be more susceptible to overuse injuries than athletes who participate in other events. Sprint and jump events require fast and explosive musculoskeletal movements that may lead to acute muscle strains. Pole-vaulters and high jumpers may be at risk for traumatic injuries to the head and spine due to improper landings. Throwing events such as the javelin, shot put, and discus are more likely to result in acute and overuse injuries to the upper extremities than other track and field events (Snouse 2002).

The purpose of this chapter is to review the existing literature on the distribution and determinants of injury rates as reported in the elite/club, collegiate, and interscholastic track and field injury and cross-country running literature, and to suggest measures for the prevention of injury and directions for future research. We restricted our review to studies covering events that were competitive in nature rather than recreational one-time sponsored running events. Incidence data as percentages were summarized over the time frame of the individual study, which ranged from a few weeks to several years. When available, incidence data were reported as the number of injuries per athlete exposure or person-years. Potential risk factors for injury were evaluated on cohort (prospective or retrospective) or case–control studies only.

The literature on injuries among competitive elite/club, collegiate, and high-school track and field and cross-country runners presented in this chapter must be evaluated in light of the following methodologic limitations:

- Information for injury rates and risk factors among Olympic level athletes was not found. Thus, findings are limited to elite/club, collegiate, and high-school populations.
- Some studies did not provide adequate data to estimate overall sample injury rates, limiting comparisons of several studies.
- Comparability within and across competitive levels are difficult, as studies often use different definitions of injury, data-collection methods, and criteria to determine the population at risk.
- Few studies used a more sensitive denominator (e.g., per 1,000 athlete exposures) that accounted for the actual number of practices and competitive events in which each athlete or runner participated.
- The few studies examining injury patterns during the season have reported the proportion of athletes injured. Without adjusting for actual athlete exposure, the incidence of injury may appear highest at the beginning of the season because there may be more participants to report an injury. As the season progresses, there may be fewer participants to report an injury because of a season-ending injury or noninjury reason (e.g., quitting the sport). Thus, the risk of injury toward the end of the season may be falsely minimized.
- In track and field, few studies reported injury rates and risk factors for specific events. Thus, determining which events have the highest risk of injury is difficult for directing prevention efforts.
- In general, information is limited for injury rates by body location, injury type, injury severity, or setting (practice vs. competitive event). In studies of multiple sports, data for these rates were usually not reported individually for track and field or cross-country.
- Few studies prospectively examined risk factors for injury at these competitive levels.

Who Is Affected by Injury?

Incidence of Injury

Overall Comparisons

A comparison of injury rates reported in prospective and retrospective studies of club/elite, collegiate, and high-school track and field athletes (n = 17) and cross-country runners (n = 15) is shown in Table 3.1. Most injury rates were determined per 100 athlete-seasons, with a range of 1.3 to 147.9 injuries per 100 athlete-seasons in track and field and 1.4 to 75.1 per 100 athlete-seasons in cross-country. However, calculating injury rates per 100 athlete-seasons does not account for individual differences in exposure risk. When determining injury risk by exposure, only three studies reported injury rates by athlete exposures (AEs), with a range of 1.1 to 29.9 per 1,000 AEs for track and field (Clarke & Buckley 1980; Powell & Dompier 2004; Knowles et al. 2006). For cross-country, four studies reported

Table 3.1 Comparison of injury rates in track and field athletes and cross-country runners.

Study	Design	Data Collection	Duration	Injury Definition	No. of Participants	No. of Injuries	Percentage of Athletes Injured	Injury Rate/100 Athlete-Seasons	Injury Rate/1,000 Athlete Exposures
Elite/Club Track									
Bennell & Crossley (1996)	R	I	12 mo	Musculoskeletal pain or injury that caused alteration of normal training ⩾1 wk	95 F: 46 M: 49	130 57 73	75.8 69.6 81.6	136.8 123.9 149.0	—
D'Souza (1994)	R	Q	12 mo	Injury lasting ⩾1 wk	147 F: 51 M: 96	90 29 61	61.2 56.9 63.5	—	—
Lysolm & Wiklander (1987)	P	ME/IRF	1 yr	Injuries affecting training or competition for ⩾1 wk	60	55	65.0	91.7[a]	
Orava & Saarela (1978)	P	ME/I	3 yr	Any treatment	48 F: 22 M: 26	71[a] 29[a] 42[a]	—	147.9[a] 131.8[a] 161.5[a]	—
Zaricznyj et al. (1980)	P	MR	1 yr	Trauma requiring first aid, school/insurance accident reports or medical treatment	289	23	—	7.9	—
Collegiate Track									
Powell & Dompier (2004)									
Indoor	P	AT	2 yr	Restricted participation or ATC evaluation required.	NA F: NA M: NA	4,977[a] 2,514 2,463	—	—	29.9[a] 30.0 29.7
Outdoor					NA F: NA M : NA	2,737[a] 1,329 1,408	—	—	17.2[a] 18.9 15.7
Lanese et al. (1990)									
Indoor	P	AT/MR	1 yr	Trauma resulting in time lost from practice or competition	94 F: 37 M: 57	44 16 28	35.1 36.8 43.2	46.8 43.2 49.1	—
Outdoor					93 F: 37 M: 56	15 4 11	14.0 10.8 16.1	16.1 10.8 19.6	—
Sallis et al. (2001)	R	AT	15 yr	Medical problem requiring ATC visit	F: NA M: NA	NA NA	—	41.6 46.8	—

Clarke & Buckley (1980)	P	AT	3 yr	Injury cause ≥1 wk missed participation	F: NA M: NA	NA NA	12.0 10.0	—	2.2 1.9
Collegiate Cross-Country									
Kelsey et al. (2007)[b,c]	P	ME/Q	1.85 yr	Stress fracture	127	22	14.2	7.7	—
Reinking et al. (2007)	P	Q	1 season	Exercise-related leg pain	88 F: 34 M: 33	26 15 11	38.8 44.0 33.0	—	—
Reinking (2006)[b]	P	ME/IRF	1 season	Exercise-related leg pain	18	9	50.0	—	—
Powell & Dompier (2004)	P	AT	2 years	Restricted participation or ATC evaluation required	NA F: NA M: NA	1,884[a] 959 925	—	—	20.1[a] 21.0 19.2
Sallis et al. (2001)	R	AT	15 years	Medical problem requiring ATC visit	F: NA M: NA	NA NA	—	34.5 31.4	—
High-School Track									
Knowles et al. (2006)	P	IRF	3 seasons	Limited participation following day of injury or required medical attention	2,269[a] F: 1,266 M: 1,003	164[a] 90 74	7.2[a] 7.1[a] 7.4[a]	—	NA 1.18 1.06
Beachy et al. (1997)	P	AT	8 years	Any symptom	2736[a] F: 1,531 M: 1,205	1,940[a] 1,120 820	50.2[a] 52.0 48.0	70.9 73.0 68.0	—
McLain & Reynolds (1989)	P	AT exam	1 season	Unable to complete practice or game or missed subsequent practice or game	135[a] F: 65 M: 70	19[a] 12 7	14.1[a] 18.5 10.0	—	—
Watson & DiMartino (1987)	P	I/Q	1 season (77 days)	Miss meet or ≥2 practices, or cause change in training for ≥2 practices	234 F: 78 M: 156	41 11 30	17.5 14.1[a] 19.2[a]	—	—
Lowe et al. (1987)	P	IRF/AT	1 season	Miss an organized practice or game	446 F: 167 M: 279	6[a] 2 4	—	1.3[a] 1.2 1.4	—
Chandy & Grana (1985)	P	TC	3 seasons	Altered ability to compete or practice in usual manner	10,642[a] F: 4,235 M: 6,407	149[a] 48 101	—	1.4[a] 1.1[a] 1.6[a]	—
Requa & Garrick (1981)	P	AT/IRF	2 seasons	Unable to complete practice or game or missed subsequent practice or game	516 208 308	174 73 101	—	33.7[a] 35.1[a] 32.8[a]	—
Shively et al. (1981)	P	TC	1 season	Altered ability to compete or practice in usual manner	2,823[a] F: 1,141 M: 1,682	36[a] 8 28	—	1.3[a] 0.7[a] 1.7[a]	—

(*continued*)

Table 3.1 (*continued*)

Study	Design	Data Collection	Duration	Injury Definition	No. of Participants	No. of Injuries	Percentage of Athletes Injured	Injury Rate/100 Athlete-Seasons	Injury Rate/1,000 Athlete Exposures
High-School Cross-Country									
Plisky et al. (2007)	P	IRF/AT	1 season (13 wk)	Unable to complete practice or game or missed subsequent practice or game due to MTSS injury	105 F: 46 M: 59	17 11 6	15.2 21.7 10.2	16.2[a] 23.9[a] 10.2[a]	2.8 4.3 1.7
Rauh et al. (2006)	P	IRF	1 season (11 wk)	Unable to complete practice or game or missed subsequent practice or game	421 F: 186 M: 235	316 157 159	38.5 41.9[a] 35.7[a]	75.1[a] 84.4[a] 67.7[a]	17.0 19.6 15.0
Bennett et al. (2001)	P/CC	I/ME	1 season (8 wk)	Symptoms of MTSS	125 F: 68 M:57	15 13 2	12.0 19.1[a] 3.5[a]	—	—
Rauh et al. (2000)	P	IRF	15 seasons	Unable to complete practice or game or missed subsequent practice or game	3,233 F: 1,202 M: 2,031	1,622 776 846	29.0 34.0 26.0	50.2[a] 64.6[a] 41.7[a]	13.1 16.7 10.9
Beachy et al. (1997)	P	AT	8 seasons	Any symptom	1,288[a] F: 787 M: 501	843[a] 512 331	47.4[a] 47.0 48.0	65.5[a] 65.0 66.1	—
McLain & Reynolds (1989)	P	AT exam	1 season	Unable to complete practice or game or missed subsequent practice or game.	94 F: 40 M: 54	10[a] 3 7	10.6[a] 7.5 13.0	—	—
Lowe et al. (1987)	P	IRF/AT	1 season	Miss an organized practice or game	188 F: 63 M: 125	3 1 2	—	1.6 1.6 1.6	—
Chandy & Grana (1985)	P	TC	3 seasons	Altered ability to compete or practice in usual manner	2,278[a] F: 711 M: 1,567	31[a] 8 23	—	1.4[a] 1.1[a] 1.5[a]	—
Shively et al. (1981)	P	TC	1 season	Altered ability to compete or practice in usual manner	576[a] F: 187 M: 389	9[a] 0 9	—	1.6[a] 0.0[a] 2.3[a]	—
Garrick & Requa (1978)	P	AT/IRF	2 seasons	Unable to complete practice or game or missed subsequent practice or game	167[a] F: 26 M: 141	50[a] 9 41	—	29.9[a] 34.6 29.1	—

AT = athletic trainer reports; ATC = certified athletic trainer; CC = case–control; F = females; I = interview; IRF = injury report form; M = males; ME = medical exam; MR = medical reports; MTSS = medial tibial stress syndrome; NA = data not available; P = prospective; Q = questionnaire; R = retrospective; TC = telecommunication between coaches and MDs.

[a] Calculated from data presented in article.

[b] Only women studied.

[c] Forty-five percent collegiate cross-country runners, 55% postcollegiate running clubs (competitive).

Table 3.2 Percentage comparison of injury by running or event types in track and field.

Study	No. of Participants	No. of Injuries	Sprinting	Distance Running	Marathon	Pole-Vaulting	High Jump	Hurdles	Shot Put	Long Jump	Before and after Practice	Other
Elite/Club												
D'Souza (1994)	147	90	30.0[a]	27.8[a,b]	—	—	—	13.3[a]	14.4[a,b]	11.1[a,b]		3.4[a,b]
Lysolm & Wiklander (1987)	60	55	38.2[a]	29.1[a,c]	32.7[a,c]	—	—	—	—	—	—	—
High School												
Watson & DiMartino (1987)	234	41	46.3	17.1	—	9.8	4.9	2.4	—	—	14.7	4.9
	F: 78	11	54.4	36.4	—	—	—	—	—	—	9.1	—
	M: 156	30	43.3	10.0	—	13.3	6.7	3.3	—	—	16.7	6.7
Requa & Garrick (1984)	516	78[d]	43.6[a]	23.1[a,e]	—	—	—	14.1	—	12.8[a,f]	—	6.4[a]
	F: 208	27[d]	66.7[a]	11.1[a,e]	—	—	—	1.1[a]	—	7.4[a,f]	—	11.1[a]
	M: 308	51[d]	31.3[a]	33.3[a,e]	—	—	—	15.7[a]	—	15.7[a,f]	—	3.9[a]

No data were reported specifically for discus or javelin events.
F = females; M = males.
[a] Calculated from data presented in article.
[b] Distance = middle and distance running; long jump = all jump events; other = multi-event; shot put = all throwing events.
[c] Distance = middle distance; marathon = both long distance and marathon running.
[d] Based on 44.8% (78/174 injuries) reported injuries specific to track events.
[e] Events >400 yd.
[f] Inclusive of all jumping activities.

injury rates by athlete exposure with a range of 2.8 to 20.1 per 1,000 AEs (Rauh et al. 2000, 2006; Powell & Dompier 2004; Plisky et al. 2007).

Event Type in Track and Field

Five studies provided information on injury occurrence by event type in track and field (Table 3.2). While Bennell & Crossley (1996) reported no significant differences between injury risk by event type (sprints/hurdles: 100 m, 200 m, 400 m; middle distance: 800 m 1500 m; distance: 3 km, 5 km, 10 km, marathon; jumps/multiple events: long, triple, high, heptathlon), they did not report injury estimates or provide data to calculate them; therefore, the study was not included in the table. Two studies provided data by event type among elite/club athletes. D'Souza (1994) reported data for running and field events and reported that most injuries occurred during sprinting and distance running events. Lysolm & Wiklander (1987) restricted their report to running events only and also found that the highest percent of injuries occurred during sprinting events.

Similar to the elite/club studies, data from two prospective high-school studies indicated that most injuries occurred during running, with the highest number reported during sprinting, followed by middle distance/distance running (Requa & Garrick 1981; Watson & DiMartino 1987).

In summary, while the data suggest that injury risk is higher among runners as compared with athletes competing in field events (Figure 3.1), several limitations must be noted. First, the data on field events is limited. Second, the definition of injury and number of athletes injured in a specific event is not standardized across the studies. Third, none of the studies used a denominator that accounted for varying exposures by event type to adequately compare injury rates between event types. Finally, the definition of what is considered a sprint or distance event (e.g., 100 m vs. 800 m) or the classification of the athlete (sprinter vs. distance runner) when injured was variable and may have affected the risk estimate reported for that event. Thus, further research to provide accurate information for each event type is needed, especially at the collegiate level, for which no reports were found.

Where Does Injury Occur?

Anatomical Location

The percentage of injuries associated with anatomical locations is presented in Table 3.3 for elite/club and high-school track and field athletes and high-school cross-country runners only. The categorization of body regions are derived from those commonly used in prospective and retrospective studies of track and field and cross-country running.

Figure 3.1 Current evidence suggests that the injury risk among track and field athletes is higher among runners than those competing in field events. © IOC / Yo NAGAYA

Table 3.3 Percentage comparison of injuries by injury location among track and field athletes and cross-country runners.

Study	**Elite/Club Track**				**High-School**				**High-School Cross-Country**		
	Bennell & Crossley (1996)	D'Souza (1994)[a,b]	Lysolm & Wiklander (1987)[a]	Orava & Saarela (1978)[a]	Zaricznyj et al. (1980)[a,c]	Watson & DiMartino (1987)	Lowe et al. (1987)	Requa & Garrick (1981)[a]	Rauh et al. (2006)	Rauh et al. (2000)	Lowe et al. (1987)
Design	R	R	P	P	P	P	P	P	P	P	P
No. of participants	95	147	60	48	289	234	446	516	421	3,233	188
Number of injuries	130	90	55	71	50	41	6	174	316	1,314[d]	3
Head	***0.0***	***0.0***	***0.0***	***0.0***	***6.0***	***0.0***	***0.0***	***1.9***	***0.0***	***0.0***	***0.0***
Spine/trunk	***0.0***	***14.7***	***0.0***	***12.7***	***6.0***	***14.6***	***16.7***	***6.3***	***4.2***	***3.2***	***0.0***
Back/spine	—	14.7	—	12.7	6.0	9.7	0.0	5.2	4.2	3.2	—
Trunk/internal	—		—	0.0	0.0	4.9	16.7	1.1	0.0	0.0	—
Upper extremity	***0.0***	***4.6***	***0.0***	***1.4***	***24.0***	***4.8***	***16.7***	***4.5***	***0.0***	***0.0***	***0.0***
Shoulder/upper arm/elbow	—	2.8	—	1.4	6.0	4.8	16.7	3.4	—	—	—
Wrist/hand/fingers	—	1.8	—	0.0	18.0	0.0	0.0	1.1	—	—	—
Lower extremity	***100.0***	***80.7***	***100.0***	***84.5***	***64.0***	***80.3***	***66.7***	***87.3***	***95.8***	***95.1***	***100.0***
Pelvis/hip/groin	13.0[c]	7.3	12.7[e]	9.9	10.0	12.1	0.0	0.0	11.7	6.6	0.0
Upper leg	21.5	20.2	18.2	12.7	0.0	7.3	16.7	29.3	5.2	6.7	0.0
Knee/patella	16.2	11.0	12.7	19.7	24.0	19.5	16.7	12.6	21.7	22.0	0.0
Lower leg	27.7	18.3	23.7	9.9	8.0	19.5	33.3	35.6	38.3	33.6	66.7
Achilles tendon	0.0	0.0	9.1	5.6	0.0	2.4	0.0	0.0	2.4	0.0	0.0
Ankle	7.3	13.8	10.9	15.4	14.0	17.1	0.0	9.8	10.8	17.1	33.3
Foot/toes	14.6	10.1	12.7	11.3	8.0	2.4	0.0	0.0	5.7	9.1	0.0
Other	*0.0*	*0.0*	*0.0*	*1.4*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*1.7*	*0.0*

[a] Calculated from data presented in article.
[b] Percentages based on total number of injuries reported for each body part.
[c] Based on organized school sport and physical education participation settings.
[d] Only 80% of all reported injured body locations.
[e] Reported as back/pelvis/hip.

The percent of injury in some body regions may be incomplete because the data from some studies could not be categorized accordingly in our classification. Despite this limitation, data in Table 3.3 indicate that the lower-extremity body region incurred the greatest percentage of injuries, followed by the spine/trunk and upper-extremity regions. Few injuries occurred to the head.

Head

Our review suggests that the incidence of head injuries is rare and occurred only in young track and field athletes (Zaricznyi et al. 1980; Requa & Garrick 1981). Neither study, however, specified the injury type or severity, event or cause of the head injuries.

Spine/Trunk

The proportion of spine/trunk injuries reported among track and field athletes was larger than that reported in cross-country runners. The difference may be because track and field has a variety of events that may cause acute and overuse spine and trunk injuries, whereas cross-country runners are more likely to incur overuse injuries only to the low back region, which absorbs high levels of force during the support phase of running and is acted on by strong muscular contractions (Knutzen & Hart 1996).

Upper Extremity

Most upper-extremity injuries occurred at the shoulder and elbow and were only reported in track and field studies (Watson & DiMartino 1980; Requa & Garrick 1981; Lowe et al. 1987; Sallis et al. 2001). This seems plausible, as acute or overuse upper-extremity injuries are more likely to occur in track and field events that comprise throwing (e.g., javelin, discus, shot put) or landing (pole-vault, high jump).

Lower Extremity

Since all track and field events and cross-country running require a significant amount of lower-extremity use, it would be expected that most injuries occur at the lower limbs because of repeated loading cycles that may not be accommodated by the musculoskeletal system. Overall, a higher proportion of lower-extremity injuries was reported among cross-country runners than among track and field athletes. For cross-country runners, the lower leg was the most common location of injury, followed by the knee and ankle. While the predominant body site of lower-extremity injury among track and field athletes was also the lower leg, injuries to the upper leg were slightly more frequent than those to the knee. The higher percent of upper-leg injuries may reflect the explosive and dynamic nature of the sprinting/hurdling and jumping events and the additional requirement of quadriceps and hamstring muscles during speed running and plyometric activities (Bennell & Crossley 1996).

Environmental Location

Practice versus Competitive Event

Although few track and field and cross-country studies reported data on the setting in which the injury occurred, those that did reported more injuries during practice (range, 1.1–75.3 injuries per 100 athletes) than in a competitive event (range, 0.2–20.0 injuries per 100 athletes) regardless of competition level (Clark & Buckley 1980; Zarincznyi et al. 1980; Requa & Garrick 1981; Lowe et al. 1987; Watson & DiMartino 1987;D'Souza 1994; Rauh et al. 2000, 2006; Knowles et al. 2006). When rates are calculated by athlete exposure, two studies (Rauh et al. 2000, 2006) show that injury rates in cross-country are greater during practice than during competition ($P \leqslant 0.05$). Although athlete exposures may not be as sensitive as athlete exposure-hours in estimating the risk of injury during practices and games (Caine et al. 2006), the higher practice injury rates per athlete exposures found in cross-country may adequately reflect the effect of cumulative mileage or longer distances run during practices than in competitions. At present, no studies have reported practice and competition injury-rate comparisons per athlete exposure-hours or per miles in track and field or cross-country.

When Does Injury Occur?

Injury Onset

In general, most injuries in track and field and cross-country running are overuse in nature (injuries caused by repetitive microtrauma to the tendons, bones, and joints that develop gradually over time). Only three studies differentiated between acute and sudden onset injuries and overuse injuries. In a study of 95 elite/club track and field athletes, Bennell and Crossley (1996) reported that 71.6% of 111 lower-limb injuries were overuse in nature, especially for middle-distance and long-distance runners (76% and 95%, respectively). Athletes participating in sprints/hurdles, and jumps/multi-events, however, were more likely to incur an acute or sudden onset injury (50% and 55%, respectively). Orava and Saarela (1978) also reported a similar distribution of acute and overuse injuries of young elite track and field athletes over a 3-year period. Of the 71 injuries reported, 52 (73.2%; 36.1 per 100 athletes/year) were overuse injuries and 19 (26.8%; 13.2 per 100 athletes/year) acute injuries. In a study of 446 high-school track and field athletes and 188 cross-country runners, Lowe et al. (1987) reported that only 1 (16.7%; 0.22 per 100 participants) of the 6 track and field injuries was acute onset. The acute injury was caused by a discus hitting a female athlete in an adjoining field. All (n = 3) cross-country running injuries were overuse in nature.

Chronometry

Only three studies provided information regarding injury patterns during the course of a competitive season. In a 1-year study of 147 elite track and field athletes, D'Souza (1994) reported that most (53.4%) injuries occurred at the beginning of the season and the least (8.9%) toward the end of the season. In a study of 3,233 high school cross-country runners, Rauh et al. (2000) reported that most injuries occurred during weeks 3 to 7 (68.7%) of a 16-week season. In a 1-year study of track and field athletes, Lysolm and Wiklander (1987) reported significant variations ($P < 0.001$ to 0.05) in the incidence of injury over the 12 months with the highest frequency of injuries during the spring and summer months when training and competition were most intense. Among long-distance/marathon runners, a significant correlation ($r = 0.59$) was found between the injury rate during a given month and the distance covered during the preceding month.

What Is the Outcome?

Injury Type

A percentage comparison of injury types by elite/club track and field (Orava & Saarela 1978; Lysolm & Wiklander 1987; Bennell & Crossley 1996) and high-school track and field (Requa & Garrick 1981; Lowe et al. 1987; Watson & DiMartino 1987), and cross-country (Lowe et al. 1987) is shown in Table 3.4. Overall, inflammations, muscle strains, and sprains were the most common injury types for these athletes. Although not summarized in Table 3.4, the most common inflammation-type injuries occurred at the lower leg (medial or posterior tibial stress syndrome, "shin splints") and knee (patellofemoral pain syndrome, knee pain). The most common body sites for muscle strains and sprains were at the hamstrings and ankle, respectively. Tendinitis at the Achilles and patellar tendon were the most common types of tendinitis injuries.

Time Loss

Currently, there is no consensus on what constitutes the severity of an injury. To provide some method of comparing the severity of injury across studies, the time lost as a result of injury has been used. In general, time loss has been defined as any injury that restricts the athlete from completing a practice or competitive event or prevents the athlete from returning to a subsequent practice or competitive event in an unrestricted participation status (Rice, Schlotfeldt & Foley 1985; Rauh et al. 2006). While time-loss severity classifications of mild (≤7 days), moderate (8–21 days), or major (≥22) have been advocated to standardize injury severity (Powell & Dompier 1994), others have used different classifications (Beachy et al. 1997; Rauh et al. 2006; Plisky et al. 2007). Thus, these differences in definitions make the comparability within and across competitive levels difficult.

Data on injury severity from one high-school track and field study and four cross-country studies are summarized in Table 3.5. Using similar injury-severity classifications, all studies comparing severity per 1,000 athlete exposures (Rauh et al. 2000, 2006; Plisky et al. 2007) or per 100 athletes (Garrick & Requa 1978; Requa & Garrick 1981;

Table 3.4 Percentage comparison of injuries by injury type among track and field athletes and cross-country runners.

Study	Design	No. of Participants	No. of Injuries	Contusion	Fracture	Inflammation	Laceration	Sprain	Strain	Stress Fracture	Tendonitis	Other
Elite/Club Track												
Bennell & Crossley (1996)[a]	R	95	130	—	—	25.2	—	5.5	24.5	20.5	11.0	13.3
Lysolm & Wiklander (1987)[a]	P	39	55	—	—	43.6	—	10.9	20.0		25.5	—
Orava & Saarela (1978)	P	48	71	2.8	—	39.4	1.4	12.7	16.9	1.4	12.7	12.7
Collegiate Track												
Clarke & Buckley (1980)	P	F: NA	NA	—	20.0	6.0	—	16.0	26.0	—	—	32.0
		M: NA	NA	—	6.0	8.0	—	18.0	48.0	—	—	20.0
High-School Track												
Watson & DiMartino (1987)	P	234	41	—	—	36.5	2.5	17.2	24.3	—	14.6	4.9
		F: 78	11	—	—	27.3	—	27.3	18.2	—	9.1	18.2
		M: 156	30	—	—	39.9	3.3	13.3	26.7	—	16.7	—
Lowe et al. (1987)[a]	P	446	6	16.7	—	—	—	16.7	66.6	—	—	—
		F: 167	2	50.0	—	—	—	—	50.0	—	—	—
		M: 279	4					25.0	75.0	—	—	—
Requa & Garrick (1981)[a]	P	516	174	1.7	2.9	17.2	2.3	15.5	46.0	—	—	14.4
		F: 208	73	2.7	4.1	19.2	—	15.1	39.7	—	—	19.2
		M: 308	101	1.0	2.0	15.8	4.0	15.8	50.5	—	—	10.9
High-School Cross-Country												
Lowe et al. (1987)[a]	P	188	3	—	66.7	—	—	33.3	—	—	—	—
		F: 63	1	—	100.0	—	—	—	—	—	—	—
		M: 125	2	—	50.0	—	—	50.0	—	—	—	—

F = females; M = males; NA = data not available or not able to be calculated from report; P = prospective; R = retrospective.
[a] Calculated from data presented in article.

Rauh et al. 2006; Plisky et al. 2007) indicate that most injuries are minor in nature. Although no data were reported in terms of injury-severity classification for elite/club athlete studies, Bennell et al. (1996) reported that average time loss from training due to injury among club track and field athletes was 9.0 days (standard deviation, 8.5).

Clinical Outcome

Reinjury

Few studies have reported on reinjury among track and field athletes and cross-country runners. Data from two track and field studies (Clarke & Buckley 1980; Bennell & Crossley, 1996) and two cross-country (Rauh et al. 2000, 2006) studies indicated that reinjury rate per 100 athletes ranged from 19.6 to 46.3. The two cross-country studies also reported reinjury rates of 37.6 and 43.3 per 1,000 athlete exposures, respectively (Rauh et al. 2000, 2006). Two studies indicated that the shin and knee had the highest rates of reinjury, (Rauh et al. 2000, 2006). While information on time lost as result of reinjury among track and field athletes and cross-country runners is limited, it constitutes important information for participants and coaches, since it represents an index of the extent to which progress toward increased skill and running levels can be compromised by injury. Because the reasons are not clear for reinjury among track and field athletes and cross-country runners, future studies should examine these factors to help explain this finding in these sports, particularly among female athletes, for whom the reinjury rates appear to be higher.

Catastrophic Injury

Catastrophic injuries are rare but severely debilitating events. Data on catastrophic injury among collegiate and high-school track and field and cross-country runners are monitored by the National Center for Catastrophic Sport Injury Research (Mueller & Cantu 2006). During 24 years of observation (1983 through 2006), 68 direct catastrophic injuries occurred in collegiate and high-school track and field. Direct injuries are those that occurred directly from participation in the skills of the sport. Most direct injuries (n = 58) occurred at the high-school level, but when adjusted for exposure (per 100,000 participants), the rates are higher for collegiate track and field athletes. In general, rates for direct injuries are higher for male than for female track and field athletes. Pole-vaulting is responsible for most injuries, with 19 fatal (18 high school, 1 college), 11 non-fatal permanent disability (8 high school, 3 college), and 7 serious (5 high school, 1 college, 1 middle school) injuries. Being struck by a thrown discus, shot put, or javelin has also resulted in 23 direct injuries to high-school track and field athletes.

Economic Cost

A review of the literature showed that only one prospective study reported the cost of injury related to competitive track and field or cross-country running in elite/club, collegiate or interscholastic populations. Knowles et al. (2007) reported that the adjusted exponentiated mean medical, human capital (medical costs + loss of future earnings), and comprehensive costs (medical costs + loss of future earnings + reduced quality of life costs) for boys' track and field athletes were $452 (95% confidence interval [CI], 334–611), $1,641 (95% CI, 1,308–2,060) and $8,620 (95% CI, 6,435–11,145), respectively. The mean estimated costs of injury for girls' track and field was lower—$377 (95% CI, 320–445), $1,619 (95% CI, 1,381–1,897), and $7,637 (95% CI, 6,674–8,740), respectively. Even though most injuries resulted in less than 1 week's loss of sports participation, these relatively minor injuries resulted in a substantial cost to society. Their findings suggest that using time lost from participation rather than cost as the primary marker of severity may be misleading.

What Are the Risk Factors?

A key to the cause, prevention, and treatment of injuries of competitive track and field athletes and cross-country runners lies in an understanding of the factors associated with injuries. A number of risk factors from cohort (prospective and retrospective) and case–control studies were identified in elite/club, collegiate and high school populations. These are summarized in Table 3.6, and highlights for intrinsic and extrinsic factors are noted below.

Table 3.5 Comparison of injury rates by severity in track and field athletes and cross-country runners.[a]

Study	No. of Participants	No. of AEs	Minor Injuries	Moderate Injuries	Major Injuries	Minor Injury Rate/100 Athletes	Moderate Injury Rate/100 Athletes	Major Injury Rate/100 Athletes	Minor Injury Rate/1,000 AEs	Moderate Injury Rate/1,000 AEs	Major Injury Rate/1,000 AEs
Collegiate Track											
Clark & Buckley (1980)[b]	F: NA	—	NA	NA	NA	—	7.0[c]	5.0	—	—	—
	M: NA	—					5.4[c]	4.6	—	—	—
High-School Track											
Requa & Garrick (1981)[b]	516	—	87[c]	59[c]	28[c]	16.9[c]	11.4[c]	5.4[c]	—	—	—
	F: 208	—	30[c]	29	14	14.4[c]	13.9	6.7	—	—	—
	M: 308	—	57[c]	30	14	18.5[c]	9.7	4.5	—	—	—
High-School Cross-Country											
Plisky et al. (2007)[d]	105	5,986	15	2	0	14.3[c]	1.9[c]	0.0[c]	2.5	0.3	0.0
	F: 46	2,533	10	1	0	21.7[c]	2.2[c]	0.0[c]	3.9	0.4	0.0
	M: 59	3,453	5	1	0[e]	8.5[c]	1.7[c]	0.0[e]	1.4	0.3	0.0[e]
Rauh et al. (2006)[d]	421	18,608	209	76	45[e]	49.6[c]	18.1[c]	10.7[c,e]	11.2	4.1	2.4[e]
	F: 186	8,008	105	30	32[e]	56.5[c]	16.1[c]	17.2[c,e]	13.1	3.7	4.0[e]
	M: 235	10,600	104	46	13[e]	44.3[c]	19.6[c]	5.5[c,e]	9.8	4.3	1.2[e]
Rauh et al. (2000)[d]	3233	1,24,063	1,197	313	215[e]	37.0[c]	9.7[c]	6.7[c,e]	9.6	2.5	1.7[e]
	F: 1202	46,572	589	134	106[e]	49.0[c]	11.1[c]	8.8[c,e]	12.6	2.9	2.2[e]
	M: 2031	77,491	608	179	109[e]	29.9[c]	8.8[c]	5.4[c,e]	7.9	2.3	1.4[e]
Garrick & Requa (1978)[f]	167	—	29[c]	21[c]	—	17.4[c]	12.6[c]	—	—	—	—
	F: 26	—	6[c]	3[c]	—	23.1[c]	11.5[c]	—	—	—	—
	M: 141	—	23[c]	18[c]	—	16.3[c]	12.8[c]	—	—	—	—

AEs = athlete exposures; F = females; M = males; NA = data not available or not able to be calculated from report.
[a] All studies used prospective designs.
[b] Minor = ≤5 days lost; moderate = 6–10 days lost; major = ⩾11 days lost.
[c] Calculated from data presented in article.
[d] Minor = ⩽4 days lost; moderate = 5–14 days lost; major = ⩾15 days lost.
[e] Major and out-for-season injuries combined.
[f] Minor = ⩽5 days lost; moderate/major = ⩾6 days lost.

Intrinsic Factors

Demographics

With respect to sex as a risk factor for injury, the data are equivocal. While female runners had a significantly greater occurrence of injuries than male runners in three studies of high school cross-country runners (Bennett et al. 2001; Rauh et al. 2006; Plisky et al. 2007) other studies found no significant sex differences (Bennell & Crossley 1996; Reinking et al. 2007).

While younger age was significantly associated with injury in a prospective study of elite runners (Kelsey et al. 2007), other elite/club or high-school studies did not find an association (Bennell et al. 1995, 1996; Bennell & Crossley 1996; Rauh et al. 2006). Grade level was not associated with injury among high-school cross-country runners (Rauh et al. 2006; Plisky et al. 2007).

Body Mass/Composition

In a prospective study of high-school cross-country runners, Plisky et al. (2007) reported that runners who had a higher body-mass index (20.2–21.6, calculated as the weight in kilograms divided by the square of the height in meters) were more likely to incur an injury than runners with a lower body-mass index (18.8–20.1). However, other studies reported no significant association (Bennell & Crossley 1996; Rauh et al. 2006; Reinking 2006). Thus, more studies are needed to determine the impact of body-mass index on injuries in these sports.

Biomechanical/Alignment

Malalignment or biomechanical insufficiencies have been speculated as risk factors for running injury. Of the malalignment and biomechanical factors identified, only four were found to be significantly associated with injury: quadriceps angle (Q-angle), leg-length discrepancy, navicular drop, and greater overall flexibility. In two prospective studies of high-school runners, those with a large Q-angle (≥20 degrees for the overall sample and girls; ≥15 degrees for boys only) were approximately twice as likely to incur an injury (Rauh et al. 2006, 2007a). Runners with a right left Q-angle difference ⩾4 degrees were also twice as likely to incur an injury as compared with those with a right–left Q-angle difference of 0 to 3 degrees (Rauh et al. 2007a).

The relationship between injury and leg-length discrepancy or greater navicular drop is less clear. While a leg-length discrepancy >0.5 cm was found to be associated with stress fracture among elite track and field athletes (Bennell et al. 1996), no association was found between a leg-length discrepancy ⩾0.5 cm among high-school cross-country runners (Rauh et al. 2006). For navicular drop, a case–control study of high-school cross-country runners indicated that runners with a medial tibial stress syndrome injury had a greater mean navicular drop than noninjured runners (Bennett et al., 2001). Conversely, two prospective studies of collegiate and high-school cross-country runners found no association between a navicular drop of >10 mm and exercise-related leg pain or medial tibial stress syndrome (Plisky et al. 2007; Reinking et al. 2007).

In a retrospective study of elite track and field athletes, those with greater overall flexibility were more likely to sustain one or more injuries over a 12-month period (Bennell & Crossley 1996). An overall flexibility index of the lower limb was determined by summating z-scores for sit-and-reach, hip rotation, calf flexibility, and ankle dorsiflexion. Athletes with a flexibility index in the highest tertile were considered to have greater overall flexibility. The authors suggested that the greater flexibility observed may reflect a greater amount of stretching in that group in an attempt to prevent a future injury.

Menstrual Problems

The relationship between menstrual history and risk of injury was reported in female elite/club and collegiate populations only. Multiple studies found an association between a history of amenorrhea or oligomenorrhea and increased risk of stress fracture or other musculoskeletal injury (Myburgh et al. 1990; Bennell et al. 1995, 1996; Kelsey et al. 2007). Because menstrual irregularities have been associated with low serum estrogen concentrations, the mechanism likely involves decreased bone density secondary to hypoestrogenemia (Drinkwater et al. 1990; Rencken et al. 1996). Studies are needed to identify causes of menstrual irregularities (e.g., low energy availability) and recommend appropriate interventions (Nattiv et al. 2007).

Table 3.6 Comparison of analytical epidemiologic injury studies of female and male track and field athletes and cross-country runners.

Study	Design	Duration	Method	No. of Participants	Purpose	Results
Elite/Club Track						
Bennell et al. (1996)	P	12 mo	I	95 F: 46 M: 49	Identify factors to predict increased risk of stress fracture	Associated with stress fracture (females only) Age of menarche (OR, 4.1; $P<0.05$) Corrected (decrease in) calf girth (OR, 4.0; $P<0.05$) Female athletes with stress fracture had significantly ($P\leq0.05$) Later age of menarche Fewer menses in past year Lower menstrual index (fewer menses/yr since menarche) Lower total body BMC Lower lumbar spine BMD Lower foot BMD Lower fat intake per kilogram of body weight Greater number of leg-length discrepancies
Bennell & Crossley (1996)	R	12 mo	I	95 F: 46 M: 49	Determine incidence, distribution, types, and severity of musculoskeletal injuries	Associated with musculoskeletal injury: Greater overall flexibility: OR=5.3 ($p<0.05$) Female athletes with musculoskeletal injury had significantly ($p\leq0.05$) Later age of menarche History of menstrual disturbance (<8 menses in any year since menarche)
Bennell et al. (1995)	R	Lifetime	Q/MR	F: 53	Determine incidence and nature of stress-fracture history	Associated with stress fracture (multivariable logistic regression): History of oligomenorrhea (OR, 6.0; $P<0.02$) Carefulness about body weight (OR, 8.0; $P<0.03$) Female athletes with stress fracture had significantly ($P \leq 0.05$) Later age of menarche Higher EAT-40 (eating disorder) score

Myburgh et al. (1990)[a]	CC	1 yr	ME	50 F: 38 M: 12	Determine whether athletes with stress fractures had lower bone density or higher incidence of risk factors for osteoporosis	Athletes with musculoskeletal injury had significantly Lower lumbar spine BMD ($P = 0.02$) Lower femoral neck BMD ($P<0.005$) Lower Ward triangle BMD ($P = 0.01$) Lower trochanter BMD ($P = 0.01$) Lower Total proximal femur BMD ($P = 0.02$) Less than 90% of age-related spine density ($P = 0.01$) Lower daily calcium intake ($P = 0.02$) Lower daily intake (percent of RDA) ($P = 0.02$) Lower weekly dairy intake ($P<0.05$) Oral contraceptive nonuse ($P<0.05$) Current amenorrhea or oligomenorrhea ($P<0.005$)
Collegiate Cross-Country						
Reinking et al. (2007)	P	1 season	Q	67 F: 34 M: 33	Identify factors associated with incidence of ERLP	History of ERLP (RR, 2.3, 95% CI, 1.0–5.4)
Kelsey et al. (2007)[b]	P	Average, 1.85 yr	ME/Q	F: 127	Identify risk factors that predict stress fracture.	Associated with stress fracture (Cox proportional-hazards models) Prior stress fracture (rate ratio, 6.4; 95% CI, 1.8–22.9) Lower whole-body BMC (rate ratio, 2.7; 95% CI, 1.3–5.9) Daily calcium intake (per 100-mg decrease) (rate ratio, 1.1; 95% CI, 1.0–1.3) Younger chronologic age (rate ratio, 1.4; 95% CI, 1.1–1.9) Younger age at menarche (rate ratio, 1.9; 95% CI, 1.2–3.2)
High-School Cross-Country						
Rauh et al. (2007a)	P	1 season (16 wk)	IRF	393 F: 171 M: 222	Determine relationships of Q-angle as risk factor for overall injury and specific injured lower limb site	Q-angle ⩾20 degrees associated with any injury: Total sample (RR, 1.7; 95% CI, 1.2–2.4) Females (RR, 1.6; 95% CI, 1.1–2.5 Knee injury (RR, 5.7; 95% CI, 2.3–14.1) ⩾8 days lost from injuries (RR, 3.8; 95% CI, 1.1–13.3)

(*continued*)

Table 3.6 (*continued*)

Study	Design	Duration	Method	No. of Participants	Purpose	Results
High-School Cross-Country						
						Q-angle ⩾15 degrees with any injury (males only) (RR, 1.5; 95% CI, 1.1–2.3) Q-angle right-left ⩾4 degrees difference with any injury (RR, 1.8; 95% CI, 1.4–2.5) Shin injury (RR, 2.4; 95% CI, 1.3–4.4) Ankle/foot injury (males only) (RR, 3.7; 95% CI, 1.2–11.4)
Plisky et al. (2007)	P	1 season (13 wk)	IRF/AT	105 F: 46 M: 59	Determine whether navicular drop and other factors associated with MTSS	Associated with MTSS (multivariable logistic regression) High BMI (OR, 7.3; 95% CI, 1.2–43.5) Female sex (OR, 2.9; 95% CI, 1.1–9.6)
Rauh et al. (2006)	P	1 season (16 wk)	IRF	421 F: 186 M: 235	Identify risk factors for running-related injury	Associated with injury (Cox proportional-hazards regression) Female sex (IRR, 1.3; 95% CI, 1.1–1.6) Q-angle ⩾20 degrees (HR, 2.4; 95% CI. 1.6–3.6) Previous summer running injury (females) (HR, 1.6; 95% CI, 1.1–2.6) Any prior running injury (males) (HR, 1.2; 95% CI, 1.0–1.5)
Bennett et al. (2001)	CC	1 season (8 wk)	I/ME	125 F: 68 M: 57	Determine relationship between lower-extremity measures and MTSS	Logistic regression analysis Greater navicular drop (predicted MTSS, 64%; $P<0.001$) Female sex (predicted MTSS, 84%; $P<0.001$) Sex and navicular drop (predicted MTSS, 74%; $P<0.003$)

AT = athletic trainer reports; BMC = bone mineral count; BMD = bone mineral density; BMI = body-mass index; CC = case–control; CI = confidence interval; EAT-40 = Eating Attitudes Test-40; ERLP = exercise-related leg pain; F = females; HR = hazard ratio; I = interview; IRF = injury report form; IRR = incidence rate ratio; M = males; ME = medical exam; MR = medical reports; MTSS = medial tibial stress syndrome; OR = odds ratio, P = prospective; Q = questionnaire; Q-angle = quadriceps angle; R = retrospective; RR = relative risk.

[a] Ninety-two percent of subjects were track or road runners.

[b] Forty-five percent collegiate cross-country runners, 55% postcollegiate running clubs (competitive).

As studies have found an association between later age of menarche and low bone mineral density (BMD) and bone mineral content (BMC) (Bennell et al. 1996, 1999), it has been suggested that later age at menarche may increase the risk for stress fracture. Findings from prospective and retrospective elite track and field athlete studies support this risk association (Bennell et al. 1995, 1996; Bennell & Crossley 1996). In contrast, Kelsey et al. (2007) reported an association between younger age at menarche and higher rates of stress fracture. However, they suggested that their finding may be related to some other aspect of bone strength associated with later age at menarche in the decreased risk of stress fracture.

Bone and Muscle Mass

Associations between lower BMD or BMC and an increased risk of stress fracture were reported in elite/club track and field athletes only. Bennell et al. (1996) prospectively identified significantly lower levels of BMD at the lumbar spine and foot and lower levels of total-body BMC among athletes with stress fracture as compared with athletes without stress fractures. In a case–control study of runners, Myburgh et al. (1990) also found significantly lower levels of lumbar-spine BMD among athletes with stress fracture. They also reported lower levels of BMD at the femoral neck and Ward triangle and less than 90% of age-related spine density among athletes with stress fractures than among athletes without stress fracture.

In a prospective study of elite track athletes, Bennell et al. (1996) found that women who incurred stress fractures had significantly less lean mass than women without stress fractures. However, the effects of less lean mass may be regionally related. Although no significant differences were found for thigh-girth values between the two groups, women with smaller corrected calf-girth values (skinfold thickness subtracted from girth measurement) were at increased risk for stress fracture. The authors suggested that smaller calf muscles may be unable to produce enough force to counteract the loading of the lower limb at ground contact and to decrease bone strain. However, using the same girth measures, Bennell & Crossley (1996) did not find an association between musculoskeletal injury in any of the eight sites measured in a retrospective study of track and field athletes. Thus, further study is needed on the role of muscle mass as a predictor of injury.

Diet and Behavioral Factors

Of the multiple dietary factors examined as risk factors, only lower daily calcium and daily fat intake levels were found to be associated with an increased risk of stress fracture in two studies of collegiate and elite/club track and field athletes (Myburgh et al. 1990; Kelsey et al. 2007). In a retrospective study of elite/club track and field athletes, Bennell et al. (1995) reported that athletes with stress fractures scored significantly higher on the Eating Attitudes Test (EAT-40) (questionnaire on bulimia, food preoccupation, and oral control, Garner and Garfinkel, 1979) and were more likely to engage in restrictive eating behavior patterns and dieting. Further, they found that athletes who were careful about their weight were eight times more likely to have sustained a stress fracture.

Prior Injury

One of the strongest intrinsic risk factors for injury at any competitive level was previous injury (Rauh et al. 2006; Kelsey et al. 2007; Reinking et al., 2007). However, none of the studies reported on the cause of prior injury. That is, they did not examine whether the increased risk was due to returning to activity before complete healing or the effects of another intrinsic (e.g., biomechanical) or extrinsic (e.g., returning to too much mileage too soon) factor.

Extrinsic Factors

Training

Training error and training experience have traditionally been thought to increase the risk of injury in competitive track and field and cross-country running. In a study of elite track and field athletes, Lysolm and Wiklander (1987) reported that 72% of the injuries were caused by training fault (excessive distance, sudden change of training routines). However, comparisons of these training factors between injured and noninjured runners were not reported. Reports from cohort and case–control studies in elite/club, collegiate, and high-school populations indicate no associations between injury and the following training factors: average training hours, running distance, summer (preseason) mileage, training type, running surface, training intensity and frequency, and frequency of competition (Myburgh et al. 1990; Bennell & Crossley 1996; Bennell et al. 1995, 1996; Rauh et al. 2006; Kelsey et al. 2007; Reinking et al. 2007). In a prospective study of 421 high-school cross-country runners, running on concrete surfaces or flat, but irregular, terrain increased the risk of injury by 12% for each mile; however, only nonsignificant statistical trends were found (Rauh et al. 2006). In addition, prospective studies of collegiate and high school cross-country runners found no association between years of competitive experience and injury (Rauh et al. 2006; Plisky et al. 2007; Reinking et al. 2007).

Footwear

Like training error, inappropriate or poor footwear has been suggested as a risk factor for injury in running sports. However, several prospective and retrospective studies of competitive track and field athlete or cross-country runners were consistent in reporting no significant association between footwear and musculoskeletal injury (Myburgh et al. 1990, Bennell & Crossley 1996; Bennell et al. 1996).

In sum, although current studies indicate that training-related factors, surface, and footwear are not important in the cause of stress fracture or other musculoskeletal injury in competitive track and field athletes and cross-country runners, more studies with larger number of participants, variation in length and type of training, actual exposure time on surfaces, and detail on how footwear was assessed are needed before definitive conclusions can be made.

What Are the Inciting Events?

A review of the literature showed that no published data exist regarding inciting events leading to injury in competitive track and field or cross-country running in elite/club, collegiate, or interscholastic populations. This may be because most injuries are repetitive rather than acute traumatic in nature.

Injury Prevention

The purpose of this review was to evaluate the risk of injury and propose some considerations for prevention among competitive track and field athletes and cross-country runners. To date, only one randomized, controlled trial has been conducted to reduce injury in competitive runners. To determine the effect of oral contraceptives on bone mass and stress fracture incidence, Cobb et al. (2007) randomly assigned 150 competitive female distance runners (intercollegiate cross-country teams, post-collegiate running clubs, and road races) to an oral contraceptive (30 μg of ethinyl estradiol or 0.3 mg of norgestrel) or control (no intervention) group. Although taking oral contraceptives was not significantly related to the incidence of stress fracture, the direction of the effect was protective (hazard ratio, 0.57; 95% CI, 0.18–1.83). Findings from a prospective observational cohort in elite female track and field athletes also found no association between oral-contraceptive use and stress fracture (Bennell et al. 1996). In contrast, a case–control study indicated a protective effect of oral-contraceptive use on the incidence of stress fracture among elite female runners (Myburgh et al. 1990). Thus, further study is needed on the benefits of oral contraceptives and reduction of stress fractures.

Our review did not identify any other nonrandomized trials designed to decrease or prevent the occurrence of injury in these competitive sports populations. Therefore, suggestions for the prevention of injury in competitive track and field athletes and cross-country runner are limited.

Injury Rates

Subsequent Injury

Although current methods of reporting injury rates provide valuable information, they do not inform how injury rates might be partially skewed by a percentage of individual athletes who are injured repeatedly. Our review indicated that few studies reported the distinction between athletes who incurred only one injury versus athletes who incurred multiple injuries during the course of a season. Because an important aspect of injury prevention is to minimize the risk of an athlete's initial injury, an equal goal should be to minimize the occurrence of subsequent injuries to the same body location (reinjury) or additional injuries to new body parts (Rauh et al. 2007b). Thus, more studies are needed to better understand the impact of subsequent injury.

Practice versus Competitive Events

More studies are needed comparing injury rates during practices and competitive events at all competitive levels using denominators that adjust for the number of athletes at risk (per 1,000 athlete exposures or 1,000 hours of exposure) or distance incurred (e.g., per mile) in each setting.

Rates for Individual Track and Field Events

Few prospective studies exist that have examined injury rates by individual track and field events, particularly for jump events (long, triple, high), pole vault, and throwing events (shot put, discus, hammer, javelin). No data were found for combined events (heptathlon, decathlon). Thus, more studies are needed to determine which events have higher injury rates and to provide injury rate information, by event type, for body location and injury type and time lost (severity) due to injury.

Body Location and Injury Type

Overall, only half the studies provided information for injured body location and about one third reported information for injury type. Further, most studies classified or grouped specific body locations into gross body regions. Because specific body locations and injury types may have different causes of injury, future studies are recommended to report rate information as least detailed categorized as possible to help determine which areas deserve more attention in terms of etiologic study or preventive-management purposes. Also, more information is needed to determine whether certain body location(s) or type of injuries have higher rates of recurrence.

Risk Factor Assessment and Injury Prevention

Biomechanical/Alignment

Several studies indicate that a large Q-angle or leg-length discrepancy may increase the risk of injury (Bennell et al. 1996; Rauh et al. 2006, 2007a). Although several reports have suggested preventive interventions such as orthotic or heel-pad use to reduce these biomechanical imbalances or structural differences (McCaw 1992; Fredericson 1996; Kuhn et al. 2002; Gross & Foxworth 2003), no studies were identified that demonstrated their protective effects against injury in these sports. Thus, well-designed randomized, controlled trials or large prospective observational studies are needed to determine whether these or other prophylactic measures are effective in minimizing injury in these competitive sport populations.

Prior Injury

Studies are needed to determine common causes of prior injury. Does returning to full training and competition before an injury is fully healed increase the risk of reinjury? Does a prior injury alter an athlete's biomechanics enough to increase the likelihood of an injury at another body site? Accordingly, education and preventive musculoskeletal program studies should be implemented and evaluated to determine their effectiveness in decreasing the recurrence of injury.

Nutrition, Menstrual, and Bone Health

Low energy availability (with or without eating disorders), amenorrhea, and osteoporosis, alone or in combination, pose significant health risks to female athletes, including stress fracture (Nattiv et al. 2007). The potentially irreversible consequences of these clinical conditions emphasize the importance for prevention and for early diagnosis and treatment. Our review indicates that several of these components were associated with stress fracture among elite competitive female track and field athletes. Future studies are needed to determine the interaction of low energy expenditure, amenorrhea, and low bone mass and their effect on injury at all competitive levels, especially among high-school athletes, for whom the period of bone-mass accrual is highest. Finally, interventions designed to increase knowledge and behaviors toward appropriate energy, calcium, and protein intake among athletes and coaches are needed to assess their effectiveness in reducing injuries.

Training

Although numerous reviews on the causes of running injuries over the past few decades suggest that training errors play a large part in these injuries (Macera 1992; van Mechelen 1995; Knutzen & Hart 1996; Yeung & Yeung 2001; van Gent et al. 2007), our review indicates that training error or experience were not associated with injury in competitive track and field athletes and cross-country runners. However, only a few prospective studies examined training errors in these competitive populations. Thus, additional large-scale prospective studies are needed to determine whether the following factors increase the likelihood of injury in these sports: training distances per week, abrupt changes in frequency or intensity of training, hard (e.g., concrete) or different surface types, terrain (e.g., banked, hills). It may be that some training error factors do not cause injury in isolation but only when in the presence of another training error factor. Thus, future studies should also examine whether interactions between two or more training error factors increase the athlete's risk of injury.

While inappropriate shoe wear and management have been suggested to increase injury among track and field athletes and runners (Snouse 2002; Fredericson 1996), little is known about these factors in competitive populations. Studies are needed to determine whether certain foot type–shoe type combinations that adversely affect the athlete's lower-limb alignment or biomechanics increase the athlete's susceptibility to injury. When should shoes be replaced? Does spike length in certain events increase the risk of injury? Do certain shoes provide insufficient shock absorption for training and events? Finally, similar to findings in military recruits and other athletic populations (Yeung & Yeung 2001), the evidence for the protective effects of stretching on injury is unsubstantiated in competitive track and field and cross-country. Future studies should determine whether certain types and frequency of stretching, or when stretching is performed, are beneficial in reducing injury in these sports.

Health Care Team/Event Management

Rice et al. (1985) advocated the need for having an appropriate health care system in place for injury prevention and management purposes prior to and during the season for all sports. However, our review did not identify any reports that determined whether using a health care team resulted in a reduction in injuries or medical costs in these sports. Further, while many colleges and elite-professional teams have full-time sports medicine teams to take care of their athletes, many high schools may not have the financial resources to employ a physician or athletic trainer (Rice et al. 1985; Aukerman et al. 2006). Thus, studies are needed to examine whether injury-management/prevention programs designed for these sports are beneficial, especially at lower levels of competition.

Track and field events usually require a large number of officials to monitor the events for safety purposes (Pendergraph et al.. 2005). Because it is likely that many event officials are not sports medicine or health care professionals, studies are needed to determine whether educating these individuals in appropriate safety protocols results in fewer injuries, especially in field events (shot put, discus, hammer, javelin, pole vault) in which the injuries may have more serious consequences (Boden et al. 2001; Pendergraph et al. 2005; Mueller and Cantu 2006).

Further Research

Standardization of Study Methods

At present, it is difficult to compare injury incidence estimates among published track and field and cross-country studies for two main reasons: (1) investigators have used different methods for collecting injury data, different injury definitions, different ways of defining and collecting data on time at risk (exposure), and different ways of estimating incidence; and (2) investigators do not report their methods in sufficient detail. Definitions range from any symptom (Beachy et al. 1997) to an occurrence that causes 1 or more weeks of missed participation (Clarke & Buckley 1980). Clearly, a standard operational definition of injury needs to be determined in order to make meaningful comparisons across studies (Zemper 2005). At a minimum, we suggest the use of a denominator that specifies actual daily practice and competitive events participated in without restriction of injury. This will provide an injury rate (per 1,000 hours of exposure) that will account for varying season lengths, and allow for better comparisons of injury risk by sex, athletic event, body location, and injury type.

This review has summarized the available literature on injuries among competitive track and field athletes and cross-country runners. Despite the popularity of these sports, they have not received much attention from medical and epidemiologic researchers. First, it is clear from this review that there is limited information on injury rates, injury location, injury type, and injury severity, particularly at elite/club, collegiate, and high-school levels. Second, there are few prospective cohort and case–control studies that have adequately examined potential risk factors for injury, especially for collegiate and high-school track and field athletes, for whom no studies were found. Finally, there is a lack of studies designed to determine the protective effects of factors suggested to reduce injuries in these sports. Thus, there is a need for large-scale epidemiologic observational and interventional studies at all competitive levels in both sports. Based on our review, we have identified important issues and future research directions for these sports.

References

Aukerman, D.F., Aukerman, M.M. & Browning, D. (2006) Medical coverage of high school athletics in North Carolina. *Southern Medical Journal* **99**, 132–136.

Beachy, G., Akau, C.K., Martinson M. & Olderr, T.F. (1997) High school sport injuries: a longitudinal study at Punahou school: 1988 to 1996. *American Journal of Sports Medicine* **25**, 675–681.

Bennell, K.L. & Crossley, K. (1996) Musculoskeletal injuries in track and field: incidence, distribution and risk factors. *Australian Journal of Science and Medicine in Sport* **28**, 69–75.

Bennell, K.L., Malcolm, S.A., Thomas, S.A., Ebeling, P.R., McCrory, P.R., Wark, J.D. & Brukner, P.D. (1995) Risk factors for stress fractures in female track and field athletes: a retrospective analysis. *Clinical Journal of Sports Medicine* **5**, 229–235.

Bennell K.L., Malcolm, S.A., Thomas, S.A., Reid, S.J., Brukner, P.D., Ebeling, P.R. & Wark, J.D. (1996) Risk factors for stress fractures in female track and field athletes: a twelve-month prospective study. *American Journal of Sports Medicine* **24**, 810–818.

Bennell, K.L., Matheson, G., Meeuwisse, W. & Brukner, P. (1999) Risk factors for stress fractures. *Sports Medicine* **28**, 91–22.

Bennett, J.E., Reinking, M.F., Pluemer, B., Pentel, A., Seaton, M. & Killian, C. (2001) Factors contributing to the development of medial stress syndrome in high school runners. *Journal of Orthopaedic and Sports Physical Therapy* **31**, 504–509.

Boden, B.P., Pasquina, P., Johnson, J. & Mueller, F.O. (2001) Catastrophic injuries in pole-vaulters. *American Journal of Sports Medicine* **29**, 50–54.

Caine, D., Caine, C. & Maffuli, N. (2006) Incidence and distribution of injuries of pediatric sport-related injuries. *Clinical Journal of Sports Medicine* **16**, 500–513.

Cavanaugh, P.R. & Lafortune, M.A. (1980) Ground reaction forces in distance running. *Journal of Biomechanics* **13**, 397–406.

Chandy, T.A. & Grana, W.A. (1985) Secondary athletic injury in boys and girls: a three-year comparison. *Physician and Sportsmedicine* **13**, 107–111.

Clarke, K.S. & Buckley, W.E. (1980) Women's injuries in collegiate sports. *American Journal of Sports Medicine* **8**, 187–191.

Cobb, K.L., Bachrach, L.K., Sowers, M., Nieves, J., Greendale, G.A., Kent, K.K., Brown, B.W., Pettit, K., Harper, D.M. & Kelsey, J.L. (2007) The effect of oral contraceptives on bone mass and stress fractures in female runners. *Medicine and Science in Sports and Exercise* **39**, 1464–1473.

D'Souza, D. (1994) Track and field athletic injuries – a one year survey. *British Journal of Sports Medicine* **28**, 197–202.

Drinkwater, B.L., Bruemner, B, & Chestnut C.H. III. (1990) Menstrual history as a determinant of current bone density in young athletes. *JAMA* **263**, 545–548

Fredericson, M. (1996) Common injuries in runners: diagnosis, rehabilitation, prevention. *Sports Medicine* **21**, 49–72.

Garner, D.M. & Garfinkel, P.E. (1979) The Eating Attitudes Test: An index of the symptoms of anorexia nervosa. *Psychological Medicine* **19**, 273–279.

Garrick, J.G. & Requa, R.K. (1978) Injuries in high school sports. *Pediatrics* **61**, 465–469.

Gross, M.T. & Foxworth, J.L. (2003) The role of foot orthoses as an intervention for patellofemoral pain. *Journal of Orthopaedic and Sports Physical Therapy* **33**, 661–670.

Hreljac, A. (2004) Impact and overuse injuries in runners. *Medicine and Science in Sports and Exercise* **36**, 845–849.

Kelsey, J.L., Bachrach, L.K., Proctor-Gray, E., Nieves, J., Greendale, G.A., Sowers, M., Brown, B.W., Matheson, K.A., Crawford, S.L. & Cobb, K.L. (2007) Risk factors for stress fracture among young female cross-country runners. *Medicine and Science in Sports and Exercise* **39**, 1457–1463.

Knowles, S.B., Marshall, S.W., Bowling, J.M., Loomis, D., Millikan, R., Yang, J., Weaver, N.L., Kalsbeek, W. & Mueller, F.O. (2006) A prospective study of injury incidence among North Carolina high school athletes. *American Journal of Epidemiology* **164**,1209–1221.

Knowles, S.B., Marshall, S.W., Miller, T., Spicer, R., Bowling, J.M., Loomis, D., Millikan, R., Yang, J., & Mueller, F.O. (2007) Cost of injuries from a prospective study of North Carolina high school athletes. *Injury Prevention* **13**, 416–421.

Knutzen, K. & Hart, L. (1996) Running. In: *Epidemiology of Sports Injuries*, Caine, D.C., Caine, C. & Lindner, K. (eds.) pp 357–386. Human Kinetics, Champaign.

Kuhn, D.R., Yochum, T.R., Cherry, A.R. & Rodgers, S.S. (2002) Immediate changes in the quadriceps femoris angle after insertion of an orthotic device. *Journal of Manipulative and Physiological Therapy* **25**, 465–470.

Lanese, R.R., Strauss, R.H., Leizman, D.J. & Rotondi, A.M. (1990) Injury and disability in matched men's and women's intercollegiate sports. *American Journal of Public Health* **80**, 1459–1462.

Lowe, E.B., Perkins, E.R. & Herndon, J.H. (1987) Rhode Island high school athletic injuries 1985–86. *Rhode Island Medical Journal* **70**, 265–270.

Lysolm, J. & Wiklander, J. (1987) Injuries in runners. *American Journal of Sports Medicine* **15**, 168–171.

Macera, C.A. (1992) Lower extremity injuries in runners: advances in prediction. *Sports Medicine* **13**, 50–57.

McCaw, S.T. (1992) Leg-length inequality: implications for running injury prevention. *Sports Medicine* **14**, 422–429.

McLain, L.G. & Reynolds, S. (1989) Sports injuries in high school. *Pediatrics* **84**, 446–450.

Mueller, F.O. & Cantu, F.C. (2007) Twenty-fourth annual report: fall 1982-spring 2006. National Center for Catastrophic Sport Injury Research. URL http://www.unc.edu/depts/nccsi [accessed on November 21, 2007].

Myburgh, K.H., Hutchins, J., Fataar, A.B., Hough, S.F. & Noakes, T.D. (1990) Low bone density is an etiological factor for stress fractures in athletes. *Annals of Internal Medicine* **113**, 754–759.

Nattiv, A., Loucks, A.B., Manore, M.M., Sanborn, C.F., Sundgot-Borgen, J. & Warren, M.B. (2007) The female athlete triad. American College of Sports Medicine position stand. *Medicine and Science in Sports and Exercise* **39**, 1867–1882.

Official Olympic games website. Athletics: URL http://www.olympic.org. [accessed on May 20, 2009].

Orava, S. & Saarela, J. (1978) Exertion injuries to young athletes. *American Journal of Sports Medicine* **6**, 68–74.

Pendergraph, B., Ko, B., Zamora, J. & Bass, E. (2005) Medical coverage for track and field events. *Current Sports Medicine Reports* **4**, 150–153.

Plisky, M.S., Rauh, M.J., Heiderscheit, B., Underwood, F.B. & Tank, R.T. (2007) An epidemiological investigation of medial tibial stress syndrome among high school cross country runners. *Journal of Orthopaedic and Sports Physical Therapy* **37**, 40–47.

Powell, J.W. & Dompier, T.P. (2004) Analysis of injury rates and treatment patterns for time-loss and non-time loss injuries among collegiate student athletes. *Journal of Athletic Training* **39**, 56–70.

Rauh, M.J., Koepsell, T.D., Rivara, F.P., Margherita, A.J. & Rice, S.G. (2006) Epidemiology of musculoskeletal injuries among high school cross-country runners. *American Journal of Epidemiology* **163**, 151–159.

Rauh, M.J., Koepsell, T.D., Rivara, F.P., Rice, S.G. & Margherita, A.J. (2007a) Quadriceps angle and risk of injury among high school cross country runners. *Journal of Orthopaedic and Sports Physical Therapy* **37**, 725–733.

Rauh, M.J., Macera, C.A., Ji, M. & Wiksten, D.L. (2007b) Subsequent injury patterns in girls' high school girls sports. *Journal of Athletic Training* **42**, 486–494.

Rauh, M.J., Margherita, A.J., Koepsell, T.D., Rice, S.G. & Rivara F.P. (2000) High school cross country running injuries: a longitudinal study. *Clinical Journal of Sports Medicine* **10**, 110–116.

Reinking, M.F. (2006) Exercise-related leg pain in female collegiate athletes: the influence of intrinsic and extrinsic factors. *American Journal of Sports Medicine* **34**, 1500–1506.

Reinking, M.F., Austin, T. & Hayes, A.M. (2007) Exercise-related leg pain in collegiate cross-country athletes: extrinsic and intrinsic risk factors. *Journal of Orthopaedic and Sports Physical Therapy* **37**, 670–678.

Rencken, M.L., Chestnut C.H. III. & Drinkwater B.L. (1996) Bone density at multiple skeletal sites in amenorrheic athletes. *JAMA* **276**, 238–240.

Requa, R.K. & Garrick, J.G. (1981) Injuries in interscholastic track and field. *Physician and Sportsmedicine* **9**, 42–49.

Rice, S.G., Schlotfeldt, J.D. & Foley, W.E. (1985) The athletic health care and training program: a comprehensive approach to the prevention and management of athletic injuries in high schools. *The Western Journal of Sports Medicine* **142**, 352–357.

Sallis, R.E., Jones, K., Sunshine, S., Smith, G. & Simon, L. (2001) Comparing sports injuries in men and women. *International Journal of Sports Medicine* **22**, 420–423.

Shively, R.A., Grana, W.A. & Ellis, D. (1981) High school sport injuries. *Physician and Sportsmedicine* **9**, 46–50.

Snouse, S.L. (2002) Track and field. In: *The Female Athlete* (Nattiv, A. & Ireland, M.L., eds.), Saunders, Philadelphia, pp. 749–756.

Subtonick, S.I. (1985). The biomechanics of running implications for the prevention of foot injuries. *Sports Medicine* **2**, 144–153.

van Gent, R.N., Siem D., van Middelkoop, M., van Os, A.G., Bierma-Zeinstra, S.M.A. & Koes, B.W. (2007) Incidence and determinants of lower extremity running injuries in long distance runners: a systemic review. *British Journal of Sports Medicine* **41**, 469–480.

van Mechelen, W. (1995) Can running injuries be effectively prevented? *Sports Medicine* **19**, 161–165.

Watson, M.D. & DiMartino, P.P. (1987) Incidence of injuries in high school track and field athletes and its relation to performance ability. *American Journal of Sports Medicine* **15**, 251–254.

Yeung, E.W. & Yeung, S.S. (2001) A systematic review of interventions to prevent lower limb soft tissue running injuries. *British Journal of Sports Medicine* **35**, 383–389.

Zaricznyj, B., Shattuck, L.J.M., Mast, T.A., Robertson, R.V. & D'Elia, G. (1980) Sports-related injuries in school-aged children. *American Journal of Sports Medicine* **8**, 318–324.

Zemper, E.D. (2005) Track and field injuries. In: *Epidemiology of Pediatric Sports Injuries* (Caine, D.J. & Maffulli, N., eds.), Karger, Basel, pp. 138–151.

Chapter 4

Badminton

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Introduction

Badminton became a competitive indoor sport with national and international tournaments toward the end of the 19th century (Levinson & Christensen 1996). The first international federation was founded in the United Kingdom in 1934. Since 2005, the office of the Badminton World Federation (BWF), comprising 164 member nations, has been located in Kuala Lumpur, Malaysia (BWF 2009).

Badminton is currently played, either competitive or recreationally, by an estimated 200 million people worldwide (Chin et al. 1995). It became a full medal Olympic sport at the 1992 Olympic Games in Barcelona, with singles and doubles events for both men and women. In the 1996 Games in Atlanta, mixed doubles were also added (IOC Sports 2008).

Badminton requires considerable accelerating and decelerating movements over the court, with strokes played from extreme postural positions, resulting in severe loading of the lower extremities and the racket arm (Figure 4.1). Even though the sport is played on all levels worldwide, there are relatively few specific studies on badminton-related injuries or epidemiology. The purpose of this chapter is to describe the known epidemiology of badminton-related injuries.

There are limitations on the interpretability of the data in this search, especially because of differences in injury definitions, which range from self-reported injuries and symptoms to seeking medical care in emergency wards or sports medicine clinics. There are also differences in study populations, which are not always specified, playing level, sports habits in particular countries, available sports medicine care, and whether injured players sought medical care.

Who Is Affected by Injury?

Both on competitive and recreational levels, badminton is considered a low-risk sport. Jørgensen & Winge (1987) found a lower injury incidence in badminton (2.9 injuries per 1,000 hours) than in contact sports such as association football (4.1 injuries per 1,000 hours), ice hockey (4.7 injuries per 1,000 hours), and handball (8.3 injuries per 1,000 hours). An overview of injury rates in studies on badminton players is shown in Table 4.1.

Incidence rates in younger players are somewhat conflicting. Backx et al. (1989) examined injury incidences in 14 different sports in Dutch school pupils aged 8 to 17 years, comparing the injury rates in the various sports with the total study population. The injury risk ratio in badminton (0.21) was the second lowest of the examined sports, and lower than in other racket sports (tennis, 0.47), net sports (volleyball, 0.56) and individual sports (swimming, 0.72; club gymnastics, 0.82). However, a study by Weir & Watson (1996) with 12-to-15-year-old Irish pupils showed that badminton had the highest injury rate (7.1 injuries per 1,000 hours) of 11 school sports examined. Both studies included contact sports as well as individual sports. The difference may be related to experience, with the Dutch pupils being

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Figure 4.1 Competitive badminton demands quick reactions, speed, coordination and stamina and places significant loads on shoulders and lower extremities. Photograph by Tobias Edbom.

Table 4.1 Injury rates in studies on badminton players.

Study	Type of Study	Player Level	No. of Cases	Injuries/1,000 Hours of Badminton
Jørgensen & Winge 1987[a]	Prospective	Competitive & recreational	229	2.9
Weir & Watson 1996[b]	Retrospective	Competitive school pupils	230	7.1
Kluger et al. 1999[c]	Retrospective	Competitive	179	1.5
Yung et al. 2007[d]	Retrospective	Competitive	253	5.4

[a] Self-reported injury that appeared in connection with badminton training or match, handicapped during play and/or required special treatment to play, or made playing impossible.
[b] Self-reported injury that caused pain, discomfort, or incapacity, which was attributed to participation in sport and which necessitated curtailment or absence from training or competition for at least 2 days.
[c] Self-reported injury that was connected with badminton play.
[d] Injury that led to consultation with a sports medicine clinic.

beginners while the Irish pupils were all competitive badminton players.

Where Does Injury Occur?

Anatomical Location

In badminton, the lower extremities account for the majority of all injuries. Injury locations are shown in Table 4.2.

Research indicates that some specific injuries are more common in badminton than in other sports. For example, badminton has been shown to account for 46% to 51% of all sports-related acute Achilles tendon ruptures in Scandinavia (Möller et al. 1996; Houshian, Tscherning & Riegels-Nielsen 1998).

Similarly badminton-related eye injury has been associated with 2% (Vinger & Tolpin 1978) to 66% (Chandran 1974) of all sports-related traumatic eye injuries in different countries (Chandran 1974; Vinger & Tolpin 1978; Barrell et al. 1981; Gregory 1986; MacEwen 1987; Fong 1994; Pardhan et al. 1995; Leivo et al. 2007). However, the incidence of eye injury in badminton appears low, ranging from 0.04 injury per 1,000 playing sessions (Barrell et al. 1981) to 0.4 injury per 1,000 players per year (Leivo et al. 2007). These values are comparable to, or lower than, other racket sports, such as tennis (0.01 injury per 1,000 sessions [Barrell et al. 1981]; 0.4 per 1,000 players per year [Leivo et al. 2007]) and squash (0.05 per 1,000 sessions; 1.3 per 1,000 players per year), or contact sports like

Table 4.2 Injury-location frequencies (%) in studies on badminton injuries.

	Prospective Studies				Retrospective Studies					
	Jørgensen & Winge 1987[a]	Krøner et al. 1990[b]	Fahlström & Patel 2007[c]	Hamid 2007[d]	Hensley & Paup 1979[e]	Klingler & Biener 1986[f]	Chard & Lachmann 1987[d]	Fahlström et al. 1998b	Kluger et al. 1999[f]	Yung et al. 2007[d]
No. of injuries	229[g,h]	217[g,h]	122[h]	469[h]	435[h]	339[h]	128[g,h]	81[g,h]	179[h]	253[h]
Head	**1.3**	**4.1**	**4.0**		**5**					**4.8**
Eye	0.9	2.3	1.6		4					
Other	0.4	1.8	2.4		1					4.8
Spine/trunk	**10.5**	**1.8**	**10.6**	**18.7**	**1**	**4.5**	**14**		**11.1**	**20.0**
Neck			5.7	1.7						
Thorax										4.0
Back	10.5	1.8	4.9	16.6	1	4.5	5		11.1	13.6
Abdomen				0.4			9			2.4
Upper extremity	**30.5**	**11.1**	**18.8**	**18.1**	**21**	**8**	**24**		**17.9**	**24.8**
Shoulder	8.7	1.4	9.0		2	2	8		3.9	12.0
Upper arm	9.6	6.9							2.2	
Elbow	7.4		8.2		9	6	13		5.0	2.4
Lower arm	3.5								3.4	7.2
Hand/wrist	1.3	2.8	1.6		6		3		3.4	3.2
Not specified				18.1	4					
Lower extremity	**57.7**	**82.9**	**66.5**	**59.9**	**56**	**67**	**43**	**85.9**	**71.0**	**50.4**
Hip/groin	4.8		8.2		4					2.4
Thigh	6.6	2.8	6.6	8.3		3			11.1	12.0
Knee	10.9	11.5	20.5	24.0	9	12	25	16.7	17.9	12.0
Crus	5.7	14.3	3.3			2		5.1	0.6	5.6
Ankle	9.2	44.2[i]	27.9[j]	17.0	43[j]	47	10	29.5	30.2	10.4
Heel/ Achilles tendon	8.7			7.0		3	3	34.6	5.0	
Foot/toes	11.8	10.1[i]	27.9[j]	3.6	43[j]		5		6.2	8.0
Not specified				**3.1**	**17**	**20.5**	**20**	**14.1**		

[a] Self-reported injury that appeared in connection with badminton training or match, handicapped during play and/or required special treatment to play, or made this impossible.
[b] Injury that caused consultation in the emergency department.
[c] Injury that caused medical consultation during ongoing badminton tournament.
[d] Injury that led to consultation with sports medicine clinic.
[e] Self-reported injury handicapping the player's performance.
[f] Self-reported injury connected with badminton play.
[g] Recreational-level player.
[h] Competitive-level player.
[i] Of the injuries, 5.3% were Achilles tendon tears; however, the authors have not described whether these injuries were classified as ankle or foot injuries.
[j] Ankle and foot injuries were not separated.

floorball (0.9 per 1,000 players per year) and rink bandy (0.8 per 1,000 players per year) (Leivo et al. 2007).

Environmental Location

Jørgensen and Winge (1987) found the injury incidence to be similar in training sessions and in match play in both elite players (3.1 and 2.3 injuries per 1,000 hours of participation, respectively) and recreational players (3.1 and 3.2 per 1,000 hours, respectively). However, a study of elite players in Hong Kong (Yung et al. 2007), reported a higher injury incidence in competition than in training for both elite seniors (3.8 vs. 2.6 per 1,000 hours) and elite juniors (5.9 vs. 2.8 per 1,000 hours).

When Does Injury Occur?

Injury Onset

A majority (67–74%) of badminton injuries in competitive players are described as overuse injuries (Jørgensen & Winge 1987; Kluger et al. 1999), and in most cases (56–73%) symptoms start gradually (Fahlström et al. 2006; Fahlström & Söderman 2007). Many injury studies focus on definitions that include seeking medical care or preventing participation. However, studies show that both competitive and recreational players remain active in badminton, even though they have ongoing symptoms or injuries, with reported prevalence ranging from 16% to 20% for shoulder injuries (Fahlström et al. 2006; Fahlström & Söderman 2007), 17% to 22% for Achilles tendon problems (Fahlström et al. 2002a,b) to 28% (location not specified; Jørgensen & Winge 1987).

Chronometry

Acute badminton injuries have been shown to be more frequent during midseason, with 69% to 81% of all acute injuries occurring during the months of October through March (Krøner et al. 1990; Fahlström et al. 1998a,b). In contrast, the occurrence of acute injuries is most often normally distributed during playing sessions (Høy et al. 1994; Fahlström et al. 1998b), although some studies indicate that acute Achilles tendon ruptures seem to occur late in playing sessions, even though no exact time frames are given (Inglis & Sculco 1981; Kaalund et al. 1989; Fahlström et al. 1998a,b).

What Is the Outcome?

Injury Type

Acute badminton injuries consist mostly of soft-tissue injuries, with sprains and joint injuries the most common injuries reported, followed by strains and tendon injuries and fractures and skin wounds. An overview of the injury types is shown in Table 4.3. The most common eye injury is hyphema (Chandran 1974; Vinger & Tolpin 1978; Gregory 1986; Kelly 1987; MacEwen 1987).

Overuse injuries in badminton are most often described as different tendinopathies or soft-tissue injuries (Hensley & Paup 1979; Klingler & Biener 1986; Jørgensen & Winge 1987; Krøner et al. 1990; Høy et al. 1994; Hamid 2007).

Time Loss

The Abbreviated Injury Scale (AIS) is a six-point scale used in casualty units. The scale describes the severity of injuries, where AIS 1 indicates minor injuries and AIS 6 is untreatable injury, which is always fatal (Jørgensen 1981). Fahlström et al. 1998b reported that 51% of acute badminton injuries treated in an emergency department in a Swedish hospital were classified as minor (AIS 1) and 49% were moderate (AIS 2). Høy et al. (1994) studied 100 badminton players treated in an emergency department in a Danish hospital. The injuries in that study were not specified, but according to the AIS scale, 17% were classified as minor (AIS 1), 56% as moderate (AIS 2), and 27% as severe (AIS 3). Only 4% of the injured players were able to return to playing badminton within 1 week, and 28% of the injured players stopped playing for at least 8 weeks.

However, most badminton injuries are not so severe that they require treatment in an emergency department. Hamid (2007) studied injured badminton players consulting a sports medicine

Table 4.3 Frequency (%) of injury types described in studies on badminton-related injuries.

	Klingler & Biener 1986[a,b]	Jørgensen & Winge 1987[c,d]	Krøner et al. 1990[c,e]	Høy et al. 1994[c,e]	Fahlström et al. 1998b[a,e]	Kluger et al. 1999[a,b]	Hamid 2007[c,f]	Yung et al. 2007[a,f]
No. of injuries	339[g]	229[g,h]	217[g,h]	100[g,h]	78[g,h]	179[g]	469[g]	253[g]
Injury classification	Acute and overuse	Acute (26%) and overuse (74%)	Acute	Acute	Acute	Acute	Acute (64%) and overuse (36%)	New (49%)[i] and recurrent (51%)
Overuse		74					36	
Sprains/joint injuries	65.5	11	58.5	55	43.6	48	26	28
Strains/tendon injuries	18	12	28.6	23	39.7	51	30.9	64
Fractures	2	1.5	5.1	5	2.6		4.9	
Skin wounds	1		5.1					
Eye contusions		1.0	2.3	3				
Contusions (not eye)		0.5						2
Not specified	13.5		0.5		14.1	1	2.2	6

[a] Retrospective study design.
[b] Self-reported injury connected with badminton play.
[c] Prospective study design.
[d] Self-reported injury that appeared in connection with badminton training or match, handicapped during play, or required special treatment to play, or made playing impossible.
[e] Injury that led to consultation with the emergency department.
[f] Injury that led to consultation with sports medicine clinic.
[g] Competitive-level player.
[h] Recreational-level player.
[i] The frequency figures are related to the new injuries.

clinic and found that as many as 92% of the injured players were back on their ordinary playing level in 7 days or less, and only 7% had more than 21 days of absence from play or modified play. Jørgensen and Winge (1987) reported a mean duration of time loss for injuries of 48 days, but that 92% of injured players were still playing badminton. Thus, although many badminton injuries may interfere with play or require treatment, they do not prevent players from participating. Similar results were seen in prevalence studies on badminton-related ongoing shoulder pain, where the symptoms affected the activities of daily living in about one third of the cases and sleep in about one fourth of the cases, but the players were still playing badminton (Fahlström et al. 2006; Fahlström & Söderman 2007).

Clinical Outcome

As mentioned above, while many badminton injuries may negatively affect players or require treatment, they usually do not prevent participation. However, Høy et al. (1994) reported that 12% of the patients in their study had to stop playing. Although the injuries were not specified, they were treated in an emergency department and classified as moderate or severe in 83% of the cases. Achilles tendon rupture seems to be the acute badminton injury with the most severe consequences, since it has been found that no players have returned to their previous activity level after being treated conservatively for acute Achilles tendon rupture (Fahlström et al. 1998a). Table 4.4 lists the outcomes

Table 4.4 Consequences at follow-up after acute badminton injuries in the lower extremities.

Diagnosis	Absence from Work, in Days	Remaining Symptoms[a]	Return to Sport[a]	Same Sports Activity Level[a]
Achilles tendon rupture—surgically treated (n = 22)[b]	49 (1–90)[c]	36%	54%[d]	36%
Achilles tendon rupture—surgically treated (n = 39)[e]	49% >42 13% >90	Not specified	82%[f]	54%
Achilles tendon ruptures—nonsurgically treated (n = 9)[b]	75 (2–180)[c]	78%	22%[d]	0%
Ankle sprains/ fractures (n = 23)[b]	24 (0–65)[c]	56%	83%[d]	74%
Knee injuries (n = 13)[b]	21 (0–90)[c]	62%	46%[d]	38%
Gastrocnemius strains (n = 4)[b]	26 (0–50)[c]	0%	100%[d]	75%

[a] The percentage in these columns are all related to all the injured players in each row.
[b] Adapted from Fahlström et al. (1998a,b); mean follow-up, 36 months; range, 10–69 months.
[c] Mean and range.
[d] Badminton play.
[e] Kaalund et al. (1989); mean follow-up, 23 months; range, 11–39 months.
[f] Any sports activity.

of different acute badminton injuries in the lower extremities.

Economic Cost

Medical consultation is sought by 21% to 81% of injured players (Fahlström et al. 2006; Fahlström & Söderman 2007). Krøner et al. (1990) reported that 62% of acutely injured players who went to a hospital outpatient department needed only a single visit, while 7% were admitted. In a similar study, Høy et al. (1994) found that 21% of acutely injured players were admitted. Retrospective self-report studies on badminton injuries have shown hospitalization frequencies of 6% (Hensley & Paup 1979) to 12% (Klingler & Biener 1986) for badminton injuries that required medical consultation.

Yung et al. (2007) calculated the cost of badminton injuries and reported a mean of 4.8 physiotherapy treatments with a cost of US$253 per injury. Elite senior players seemed to need more physiotherapy treatments (5.1 per injury) than younger players (4.3 per injury).

Absence from work has been reported in 56% to 72% of injuries, with 40% of the cases being more than 3 days and 23% more than 3 weeks, with a mean of 2.4 to 42.5 days (Klingler & Biener 1986; Jørgensen & Winge 1987; Høy et al. 1994; Fahlström et al. 1998a,b). However, most studies do not specify consequences according to different diagnoses. Table 4.4 shows the mean and range for work absences for four acute lower-extremity badminton injuries.

Høy et al. (1994) reported some kind of financial loss for 10% of injured players with injuries that needed acute care, 83% of which were classified as moderate or severe.

What Are the Risk Factors?

Intrinsic Factors

Few studies have examined sex differences in injury characteristics in badminton. Jørgensen and Winge (1987) found no significant difference in injury incidence in men and women (3.0 vs. 2.8 injuries per 1,000 hours) and this finding has been reported in competitive players (Yung et al. 2007) and school pupils (Backx et al. 1989; Weir & Watson 1996). However, Klingler and Biener (1986) reported a higher frequency of ankle sprains in women as compared with men (56% vs. 44% of all injuries) and Fahlström et al. (2006) found that the frequency of players seeking medical consultations because of shoulder pain was significantly higher in female than male elite players (100% vs. 55%).

Age has been proposed as a risk factor for injury in badminton players, with older athletes at greater risk (Høy et al. 1994; Yung et al. 2007). A Danish study on recreational and competitive players (Høy et al. 1994) reported a higher incidence of injuries for players ≥18 years of age than for those <18 (>25 years = 42 injuries per 1,000 players per year; 18–25 years = 45 injuries per 1,000 players per year; <18 years = 28 injuries per 1,000 players per year). However, the differences were not statistically verified. A similar pattern was reported by Yung et al. (2007) in a study from Hong Kong, with a higher injury incidence (7.4 injuries per 1,000 hours) in elite senior athletes (≥21 years and in scholarship programs for intensive training), while elite junior athletes (<21 years recommended to join the elite senior team) had an injury incidence of 5.0 injuries per 1,000 hours. Younger potential athletes (<15 years and in systematic training in badminton) had an even lower incidence of 2.1 injuries per 1,000 hours. Fahlström et al. (2002a) found that competitive players with Achilles tendon pain were significantly older than players without pain.

Kluger et al. (1999) concluded that the incidence for acute injury in competitive badminton players increased constantly from the first competition year (0.32 injury per 1,000 playing hours) to be threefold higher during competition years 5 to 7 (0.92 injury per 1,000 playing hours); however, the authors did not report whether the differences were statistically significant. Overuse injuries showed a similar incidence during the first competition year as compared with competition years 5 to 7 (0.95 vs. 0.75 injuries per 1,000 playing hours).

Extrinsic Factors

Since a majority of badminton injuries are localized in the lower extremities, court surfaces and footwear are potentially of high importance. Although several authors have discussed these factors (Mills 1977; Jørgensen & Winge 1987; Kluger et al. 1999; Hamid 2007), no scientific studies have specifically investigated them in badminton. Furthermore, there are no studies examining technique or racket quality in relation to injuries.

Competition format is a risk factor for injury in badminton. Although most injuries (53–62%) have been documented during singles play (32–44% during doubles; Hensley & Paup 1979; Jørgensen & Winge 1987), the risk for eye injury is higher in doubles play, since being hit by the other player's racket is responsible for 7% to 31% of eye injuries (Hensley & Paup 1979; Barrell et al. 1981; Gregory 1986; Kelly 1987).

What Are the Inciting Events?

Most acute injuries (62–65%) are related to players falling or slipping on the court. The rest are due to collision or being hit by another player's racket during doubles play (Hensley & Paup 1979; Krøner et al. 1990).

A shuttle causes a majority of the eye injuries (69–83%), while a racket is responsible in the remainder of cases (Hensley & Paup 1979; Barrell et al. 1981; Gregory 1986; Kelly 1987).

Injury Prevention

Wearing protective glasses seems to be effective for eye-injury prevention in badminton, as no eye injuries have been noted in players wearing protective glasses (Chandran 1974; Vinger & Tolpin 1978; Barrell et al. 1981; Gregory 1986; MacEwen 1987; Fong 1994; Pardhan et al. 1995; Leivo et al. 2007). However, there are no prospective studies to confirm this.

Adolescent badminton players have been shown to have higher bone mineral density and size in weight-bearing sites as compared with ice hockey players, who are training on a significantly higher level, indicating a great osteogenic potential in badminton play (Nordström et al. 1998, 2008).

Further Research

The true incidences of injuries related to age, playing level, amount and intensity of badminton activity, and other risk factors is largely unknown and requires large-scale, long-term prospective studies and the development of appropriate definitions of reportable injuries to uncover them. The BWF recommends injury registrations during major badminton events. A registration form has been developed, in which all injuries that cause medical contacts during a badminton competition are registered, but this form has not been used systematically to date. This kind of registration is well positioned to gather comprehensive data, on all levels of competition, to create a basis for research on injury patterns in badminton.

Existing research has provided promising directions for study. For example, the Danish study by Jørgensen and Winge (1987) indicated a higher injury incidence in recreational players (3.1 injuries per 1,000 playing hours) as compared with elite players (2.8 injuries per 1,000 hours) but no statistical comparisons were presented, and Krøner et al. (1990) reported a shorter warm-up time for older players as compared with younger players, although the relationship between warming up and stretching habits and injury has yet to be fully explored (Kaalund et al. 1989; Høy et al. 1994; Fahlström et al. 1998a,b; Kluger et al. 1999).

Poor muscle strength has been suggested to influence injury incidence. Couppé et al. (2006) found that female senior elite badminton players had weaker external rotation strength in the shoulder as compared with junior female players. This could affect the incidence of shoulder injuries, since shoulder muscle imbalance of the external rotator cuff muscles versus the internal rotator cuff muscles is suggested to be a primary risk factor for glenohumeral-joint injuries in sports with overhead activity (Niederbracht et al. 2008). These data need to be verified in epidemiologic studies of shoulder injury in badminton.

Fatigue is also proposed to be a risk factor for badminton injuries. The overall injury incidence in elite players reported by Jørgensen and Winge (1987) was relatively low (2.8 injuries per 1,000 hours) as compared with a study of elite players in Hong Kong, where the overall injury incidence was 5.0 injuries per 1,000 hours (Yung et al. 2007). However, the total badminton-playing time in the Danish study was relatively low, with elite players training for a mean of 5.2 hours per week and playing matches 2.9 hours per week, as compared with the Hong Kong sample, in which both training time (17.4–19.1 hours per week) and match time (1.8–4.3 hours per week) were higher.

In addition, because research indicates that the majority of acute Achilles tendon ruptures occur toward the end of playing sessions, it has been suggested that fatigue and poor muscle coordination may be associated with a risk of tendon rupture (Kaalund et al. 1989; Fahlström et al. 1998b). However, methodologically sound research is needed to investigate this contention.

Previous injury and inadequate rehabilitation have also been implicated as risk factors, with 9% to 26% of injured players reporting previous pain, symptoms or injuries related to the subsequent injury location (Kaalund et al. 1989; Høy et al. 1994; Fahlström et al. 1998a,b). Yung et al. (2007) found 51% of the injuries in competitive players to be recurrent, with the frequency in elite senior athletes being 62%, in elite junior athletes 32% and in potential athletes 20%, yet no studies have been conducted to examine this relationship.

The badminton scoring system has been changed twice since 2001, which has led to more critical points as well as shorter games and matches. It is not known whether these changes have influenced injury patterns.

There are few data and no specific studies on injury prevention in badminton. As noted previously, because many injuries are recurrent or preceded by local symptoms (Kaalund et al. 1989; Høy et al. 1994; Fahlström et al. 1998a,b; Yung et al. 2007), strength-training programs and adequate rehabilitation of ongoing injuries are considered important measures to prevent injury. However, there are no prospective studies to confirm this.

In summary, there is a lack of knowledge about badminton-specific risk factors, prevention, and rehabilitation. Systematic research in these areas is most appropriate for the development of badminton in the future and should be supported by the BWF, even though prospective scientific studies in collaboration with coaches and badminton teams may be best managed on a continental or national basis.

References

Backx, F.J.G., Wietze, B.M.E., Kemper, A.B.A. & Verbeek, A.L.M. (1989) Sports injuries in school-aged children: an epidemiologic study. *American Journal of Sports Medicine* **17**, 234–240.

Barrell, G.V., Cooper, P.J., Elkington, A.R., MacFadyen, J.M., Powell, R.G. & Tormey, P. (1981) Squash ball to an eye ball: the likelihood of squash players incurring an eye injury. *British Medical Journal* **283**, 893–895.

BWF website. (2009) URL http://www.internationalbadminton.org/page.aspx?id=11196 (accessed May 31, 2009).

Chandran, S. (1974) Ocular hazards of playing badminton. *British Journal of Ophthalmology* **58,** 757–760.

Chard, M.D. & Lachmann, M.A. (1987) Racquet sports—patterns of injury presenting to a sports injury clinic. *British Journal of Sports Medicine* **21**, 150–153.

Chin, M-K., Wong, A.S.K., So, R.C.H., Siu, O.T., Steininger, K. & Lo, D.T.L. (1995) Sport specific fitness testing of elite badminton players. *British Journal of Sports Medicine* **29**, 153–157.

Couppé, C., Fahlström, M., Bjordal, J.M., Baun, M., Nielsen, D., Magnusson, P. & Aagard, H. (2006) Shoulder strength profile of junior and senior elite badminton players. Presented at Dansk Idraetsmedicinsk Årskongres, February 2–4, 2006, Copenhagen.

Fahlström, M., Björnstig, U. & Lorentzon, R. (1998a) Acute Achilles tendon rupture in badminton. *American Journal of Sports Medicine* **26**, 467–470.

Fahlström, M., Björnstig, U. & Lorentzon, R. (1998b) Acute badminton injuries. *Scandinavian Journal of Medicine and Science in Sports* **8**, 145–148.

Fahlström, M., Lorentzon, R. & Alfredson, H. (2002a) Painful conditions in the Achilles tendon region – a common problem in middle-aged competitive badminton players. *Knee Surgery, Sports Traumatolology, Arthroscopy* **10**, 57–60.

Fahlström, M., Lorentzon, R. & Alfredson, H. (2002b) Painful conditions in the Achilles tendon region in elite badminton players. *American Journal of Sports Medicine* **30**, 51–54.

Fahlström, M. & Patel, A. (2007) *Medical report Sudirman Cup world team badminton* Badminton World Federation, Glasgow, Scotland.

Fahlström, M. & Söderman, K. (2007) Decreased shoulder function and pain common in recreational badminton players. *Scandinavian Journal of Medicine and Science in Sports* **17**, 246–251.

Fahlström, M., Yeap, J.S., Alfredson, H. & Söderman, K. (2006) Shoulder pain—a common problem in world-class badminton players. *Scandinavian Journal of Medicine and Science in Sports* **16**, 168–173.

Fong, L.P. (1994) Sports-related eye injuries. *The Medical Journal of Australia* **160**, 743–750.

Gregory, P.T.S. (1986) Sussex Eye Hospital sports injuries. *British Journal of Ophthalmology* **70**, 748–750.

Hamid, S. (2007) Abstract: Epidemiology – badminton related injuries. *Badminton sports medicine seminar, 12 August 2007, Kuala Lumpur.* BWF & Malaysian Society of Sports Medicine.

Hawkins, J.M. & Allen, R. (1991) *The Oxford Encyclopedic English Dictionary*, Clarendon Press, Oxford, p. 103.

Hensley, L.D. & Paup, D.C. (1979) A survey of badminton injuries. *British Journal of Sports Medicine* **13**, 156–160.

Houshian, S., Tscherning, T. & Riegels-Nielsen, P. (1998) The epidemiology of achilles tendon rupture in a Danish county. *Injury* **29**, 651–654.

Høy, K., Lindblad, B.E., Terkelsen, C.J., Helleland, H.E. & Terkelsen, C.J. (1994) Badminton injuries—a prospective epidemiological and socioeconomic study. *British Journal of Sports Medicine* **28**, 276–279.

Inglis, A.E. & Sculco, T.P. (1981) Surgical repair of ruptures of the tendo Achillis. *Clinical Orthopaedics and Related Research* **156**, 160–169.

IOC Sports website. (2008) URL http://www.olympic.org/uk/sports/programme/index_uk.asp?SportCode=BD (accessed April 17, 2008)

Jørgensen, K. (1981) Use of the abbreviated injury scale in a hospital emergency room. *Acta Orthopaedica Scandinavica* **52,** 273–277.

Jørgensen, U. & Winge, S. (1987) Epidemiology of badminton injuries. International *Journal of Sports Medicine* **8**, 379–382.

Kaalund, S., Lass, P., Høgsaa, B. & Nøhr, M. (1989) Achilles tendon rupture in badminton. *British Journal of Sports Medicine* **23**, 102–104.

Kelly, S.P. (1987) Serious eye injury in badminton players. *British Journal of Ophthalmology* **71**, 746–747.

Klingler, K. & Biener, K. (1986) Badminton-Sportunfälle. *Schweizerische Zeitschrift für Sportmedizin* **34**, 161–165.

Kluger, R., Stiegler, H. & Engel, A. (1999) Das Trainingsalter—ein neuer Risikofaktor akuter Badmintonverletzungen. *Sportverletzung Sportschaden* **13**, 96–101.

Krøner, K., Schmidt, S.A., Nielsen, A.B., Yde, J., Jakobsen, B.W., Møller-Madsen, B. & Jensen, J. (1990) Badminton injuries. *British Journal of Sports Medicine* **24**, 169–172.

Leivo, T., Puusaari, I. & Mäkitie, T. (2007) Sports-related eye injuries: floorball endangers the eyes of young players. *Scandinavian Journal of Medicine and Science in Sports* **17**, 556–563.

Levinson, D. & Christensen, K. (1996) *Encyclopedia of World Sport.* ABC-CLIO, Santa Barbara, CA.

MacEwen, C.J. (1987) Sport associated eye injury: a casualty department survey. *British Journal of Ophthalmology* **71**, 701–705.

Mills, R. (1977) Injuries in badminton. *British Journal of Sports Medicine* **11**, 51–53.

Möller, M., Åström, M. & Westlin, N.E. (1996). Increasing incidence of Achilles tendon rupture. *Acta Orthopaedica Scandinavica* **67**, 479–481.

Niederbracht, Y., Shim, A.L., Sloniger, M.A., Paternostro-Bayles, M. & Short, T.H. (2008) Effects of a shoulder injury prevention strength training program on eccentric external rotator muscle strength and glenohumeral joint imbalance in female overhead activity athletes. *Journal of Strength and Conditioning Research* **22,** 140–145.

Nordström, A., Högström, M. & Nordström, P. (2008) Effects of different types of weight-bearing loading on bone mass and size in young males: a longitudinal study. *Bone* **42**, 565–571.

Nordström, P., Pettersson, U. & Lorentzon, R. (1998) Type of physical activity, muscle strength, and pubertal stage as determinants of bone mineral density and bone area in adolescent boys. *Journal of Bone and Mineral Research* **12**, 1141–1148.

Pardhan, S., Shacklock, P. & Weatherill, J. (1995) Sport-related eye trauma: a survey of the presentation of eye injuries to a casualty clinic and the use of protective eye-wear. *Eye* **9**(suppl), 50–53.

Vinger, P.F. & Tolpin, D.W. (1978) Racket sports. An ocular hazard. *JAMA* **239**, 2575–2577.

Weir, M.A. & Watson, A.W.S. (1996) A twelve month study of sports injuries in one Irish school. *Irish Journal of Medical Science,* **165,** 165–169.

Yung, P.S.-H., Chan, R.H.-K., Wong, F.C.-Y., Cheuk, P.W.-L. & Fong, D.T.-P. (2007) Epidemiology of injuries in Hong Kong elite badminton athletes. *Research in Sports Medicine* **15**, 133–146.

Chapter 5

Baseball

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Introduction

Millions of people worldwide participate in the sport of baseball. In the United States alone, there are approximately 2,850 professional players (including both major and minor leaguers), 45,000 intercollegiate players, 433,684 high-school players, and nearly 2 million youth players (Seefeldt et al. 1993).

Baseball's history as a medal sport in the Olympics has been brief, but its history as an Olympic exhibition/demonstration sport dates back over 100 years. The sport made its unofficial debut during the 1904 Summer Olympics. In the years since, it has been a part of 12 additional Olympiads (as both an exhibition and a medal sport) allowing 17 different nations to make appearances. Baseball was granted status as a full medal sport by the International Olympic Committee for the 1992 Barcelona games. Since then it has been a part of every Olympic Games. In 2005, baseball and softball were voted out of the 2012 Summer Olympics in London, England, making them the first sports eliminated from the games since polo was removed from the 1936 games in Berlin, Germany. The format of the sport during the games has changed very little. The only major change that has occurred was in 2000, when athletes were no longer required to be of amateur status, as previous games had required (Olympic Movement 2007).

Baseball is characterized as a noncontact sport, and historically, it has not been considered to have a high rate of injury. However, because of the sheer numbers of athletes participating, the number of injuries in baseball is substantial, and prevention of these injuries should have the utmost priority (Lyman & Fleisig 2005, Pasternack et al. 1996).

The purpose of this chapter is to comprehensively review the epidemiology of both overuse and acute injuries in the sport of baseball.

Many previously published studies on baseball injuries suffer from methodologic problems, described by Walter and Hart (1990), which restrict the potential to interpret and compare findings. These include the following: recall bias, study-population diversity, underestimation of injury, and lack of a uniform injury definition. In addition, injury rates are rarely calculated using the same rate denominator. Many studies calculate injury rates based on exposure, rather than on participation, disregarding the fact that exposure may differ for each participant. A majority of the studies on baseball-related injuries were retrospective case or case series and few used a cross-sectional or prospective design. This chapter will focus solely on retrospective and prospective cohort studies.

Who Is Affected by Injury?

A comparison of injury rates reported in prospective and retrospective injury studies, among varying levels of competition, are shown in Table 5.1. A majority of the reported rates, particularly those involving youth and high-school athletes, are reported per 100 athletes and do not account for differences in exposure. However, comparison of

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Table 5.1 Comparison of injury rates in baseball.

Study	Duration, in yr	Design	Data Source	Total Participants	Injury Definition	No. of Injuries	Injuries per 100 Athletes	Injuries per 1,000 AE	Injuries per 1,000 Population
Youth									
Hale (1961)	5	R	Insurance records	771,810	Require medical attention and insurance claim—LL insurance	15,444	2.0		
Chambers (1979)	1	P	Survey	740	Require medical treatment	2	0.27		
Zaricznyj et al. (1980)	1	R	Survey	137	Require first aid, medical attention, or insurance report	13	9.5		
Pasternack et al. (1996)	1	P	Survey	2,861	Require medical care or missed time or position restriction	81	2.8		
Cheng et al. (2000)	2	P	ER records	64,075	Required emergency room visit, hospitalization, or death	76			0.74[a]
Radelet et al. (2002)	2	P	Survey	534	Require removal from participation, first aid, or an injury for which the coach was brought onto the field of play	117		0.17	
Marshall et al. (2003)	3	R	Insurance records	6,744,240	Require insurance claim—LL insurance	4,233	0.062		
High School									
Garrick & Requa (1978)	2	P	Survey	249	Require missing practice or game	46		0.18	
Grana (1979)	2	R	Survey	1,969	Require altered participation in game or practice	29	1.47		
Lowe et al. (1987)	2	R	Survey	256	Require missing practice or game	3	1.22		
Martin et al. (1987)	2[b]	P	Survey	148	Require withholding athlete from competition	8	5.4		
McLain & Reynolds (1989)	2	P	Survey	68	Require not returning to immediate play	10	15.0		
DuRant et al. (1992)	2	P	Survey	108	Require seek medical attention and/or miss one or more games	21	19.4		
Powell & Barber-Foss (2000)	3	P	Surveillance system	2,167	NATA Injury Surveillance[c]	861	13.2		
College									
Whiteside (1980)	2	R	Surveillance system	—	Require stop participation through day of onset or substantial professional attention	133		2.9	

Clarke & Buckley (1980)	3	P	Surveillance system	—	Require miss 1 wk of participation	—	9.2		
Splain & Rolnick (1984)	3	R	Trainers' logs	88	Require injury evaluated by trainer	63	71		
Duda (1987)	1	R		—	Require missing at least one game or practice	—		3.37	
McFarland & Wasik (1998)	3	P	Surveillance system	93	Require altered participation in game or practice	277	5.83[c]	5.83	
Dick et al. (2007)	16	P	Surveillance system	—	NCAA ISS[d]	4,453 games		5.78	
						3,893 practices		1.85	
Professional/ Olympic									
Chambless et al. (2000)	12	P	End-of-season reports	1,728[e]	Require missing one or more days or games	1,049	54.5[e]		
Junge et al. (2006)	1	P	Surveillance system	1,536[f]	Require medical attention	16	1.04[f]		
Mixed									
Burt & Overpeck (2000)[g]	1	R	ED records	U.S. population	NHAMCS[h]	245,000			3.2
Conn et al. (2003)	2	R	NHIS	U.S. population	NHIS[i]	339,000			2.8

AE = athletic event; ER = emergency room; LL = Little League Baseball; NATA = National Athletic Training Association ; NCAA ISS = National Collegiate Athletic Association Injury Surveillance System; NHAMCS = National Hospital Ambulatory Medical Care Survey; NHIS = National Health Interview Survey; P = prospective; R = retrospective.

[a] Per 1,000 adolescents 10 to 19 years of age.

[b] Followed one high-school baseball tournament.

[c] The NATA Injury Surveillance system defines a reportable injury as: (1) any injury that causes cessation of participation in the current game or practice and prevents the player's return to that session, (2) any injury that causes cessation of a player's customary participation on the day after the onset, (3) any fracture that occurs, even though the athlete does not miss any regularly scheduled session, (4) any dental injury, and (5) any mild brain injury that requires cessation of a player's participation for observation.

[d] The NCAA ISS defined injury as: (1) a result of participation in an organized intercollegiate practice or competition and (2) required medical attention by a team-certified athletic trainer or physician and (3) resulted in restriction of the student-athlete's participation or performance for 1 or more calendar days beyond the day of injury.

[e] Original rate was reported as 1.79 per 10 games. Assuming a 24-man roster on each team, we calculated a new injury rate as 54.5 per 100 players.

[f] Original rate was reported as 29 per 1,000 player matches. Assuming a 24-man roster on each team, we calculated a new injury rate as 1.04 per 100 players.

[g] Includes data related to softball injuries.

[h] NHAMCS defined injury as any visit to the emergency department in which a record of cause of injury, injury diagnosis, or any reason for visiting for which injury was indicated.

[i] NHIS includes all medically attended sports-related injury episodes (any traumatic event during the past 3 months that caused an injury from an external cause during sports).

these rates is difficult because of extreme differences in injury definitions.

Youth Baseball

For this review, youth baseball was categorized as pre–high-school recreational league play. The first known epidemiologic study of baseball injuries in children was completed by Hale in 1961. The study was a retrospective review of insurance claims (specifically, only claims filed through the Little League Baseball insurance system) over a 5-year period and reported an injury rate of 2.0 injuries per 100 participants (Hale 1961). This rate is most likely an underestimate of the true injury rate because it includes only injuries in which an insurance claim was filed with Little League Baseball. Many more youth were likely injured without seeking medical care or sought care through additional insurance systems and were not included in this study (Lyman & Fleisig 2005).

Smaller studies demonstrate a wide disparity of injury rates in youth baseball ranging from 0.062 per 100 athletes to 9.5 per 100 athletes (Chambers 1979; Zaricznyj et al. 1980; Pasternack et al.1996; Marshall et al. 2003). The defining characteristics of an injury in each study can be found in Table 5.1. Cheng et al. (2000) reported 76 baseball-related emergency-room visits in 2000 among adolescents during a 2-year study in Washington, DC. This translated to an injury rate of 0.74 per 1,000 adolescents. However, not all DC youths played baseball, causing this rate to not be directly comparable to other rates presented here.

Radelet et al. (2002) used athlete exposures (AEs), rather than a person-based rate denominator, making the results not directly comparable to the other studies presented. Regardless, an injury rate of 0.17 per 1,000 AEs was found, with an injury defined as a player being removed from play, requiring first aid, or both, and is likely the most representative study of the true injury rate in youth baseball.

High-School Baseball

The first known study of high-school baseball injuries was published by Garrick and Requa in 1978 and used AE as a rate denominator rather than counts of athletes or games. Garrick and Requa showed an injury rate of 0.18 per 1,000 AEs. Compared with injuries in youth baseball, these findings are very similar, using comparable methods, to rates found by Radelet et al. (2002). Two retrospective studies found injury rates of 1.2 to 1.47 per 100 athletes (Grana 1979; Lowe et al. 1987), and several prospective studies found rates from 5.4 (in a single tournament) to 19.4 per 100 athletes (Martin et al. 1987; McLain and Reynolds 1989; DuRant et al. 1992). Perhaps the best estimate of the true incidence of baseball injuries in high-school athletes followed 2,167 high school players prospectively for three seasons. Data were collected on any traumatic event that caused an injury requiring treatment and an injury rate of 13.2 per 100 athletes was calculated (Powell and Barber-Foss 2000).

Prospective follow-up studies on high-school players have found injury rates of $\geq$9 per 100 athletes, while retrospective studies have found rates $<$2 per 100 athletes. The large disparity between retrospective and prospective studies on high-school baseball injuries suggests that a universally accepted definition of injury must be identified. It is also likely that retrospective studies are limited by recall bias (Lyman & Fleisig 2005).

Collegiate Baseball

Our literature search revealed five studies on baseball-related injuries at the collegiate level. The first, by Clarke and Buckley (1980), examined injuries reported by the National Athletic Injury/Illness Reporting System between 1975 and 1978. They reported an incidence of 9.2 significant injuries per 100 athletes. A "significant injury" in this study was defined as an injury in which an athlete missed at least 1 week of participation from that sport (Clarke & Buckley 1980).

By following one collegiate team for 4 years, Splain and Rolnick (1984) found an injury rate of 71 per 100 athletes. This rate is much higher than all other reported injury rates. A likely reason is that "injury" was defined as any evaluation done by an athletic trainer, either on the field or in the training room, including very minor injuries (Splain & Rolnick 1984).

McFarland and Wasik (1998) conducted a 3-year prospective study on a single National Collegiate Athletic Association (NCAA) Division

I team. The injury rate reported in this study was 5.83 per 1,000 AEs. In addition, through the NCAA Injury Surveillance System, Dick et al. (2007) reported an injury rate during collegiate baseball games of 5.78 and during practices of 1.85 per 1,000 AEs from 1988 through 2004. These two studies are very similar in their reported rates of injuries in collegiate baseball and represent the most accurate estimate of the collegiate baseball injury rate because of their large numbers and length of time studied.

Studies of different levels of collegiate players have revealed higher injury rates, both in games and practices, at higher levels–in games: Division I, 6.64 per 1,000 AEs; Division II, 5.36; and Division III, 4.85; in practices: Division I, 2.34; Division II, 1.47; and Division III, 1.59 (Dick et al. 2007).

Professional/Olympic Baseball

Few studies reviewed the epidemiology of injuries in professional baseball. In 2000, Chambless et al. published a 12-year (1985–1997) study on minor league baseball injuries. An “injury” was defined as an event that would cause a player to miss one or more days or games. The study showed an injury rate of 1.79 per 10 games. In addition, Junge et al. (2006) studied the 2004 Olympic Games in Athens, Greece and found an injury rate of 29 per 1000 player games, which translated to 0.5 injury per game. An injury in this study was any event that required medical attention. The paucity of published studies on injuries in professional baseball may be due to the fact that the business aspect of professional sports often has a negative impact on the reporting of such injury information to the medical community (Oberlander et al. 2000).

Chambless et al. (2000) studied injury events that required the athlete to miss one or more days or games, at the minor league level and found significantly greater injury rates at the minor league rookie level (2.4 per 10 games) than at higher minor league levels (1.62 per 10 games). These findings suggest that the rookie-level players are not conditioned enough for the professional level that they are now playing or that the players are now going above and beyond what they are physically capable of in order to be successful in professional baseball.

Injuries to Pitchers

The repetition of the high forces and torques in the shoulder and elbow experienced by pitchers can eventually result in serious injury or arm-related disability (Francis et al. 1978; Dillman et al. 1993; Fleisig et al. 1995, 1996; Hutchinson & Ireland 2003). Based on our review, studies analyzing injuries to pitchers use self-reported pain or time lost or both as their injury definition. Pitchers have the highest probability of injury (Redbook 2003). Several studies have found high rates of pain in the elbow and shoulder joints, which are thought to be a result of overuse (Figure 5.1). Summaries of studies involving elbow and shoulder injuries in pitchers can be found in Table 5.2. The first study on pitching-specific injuries compared three groups

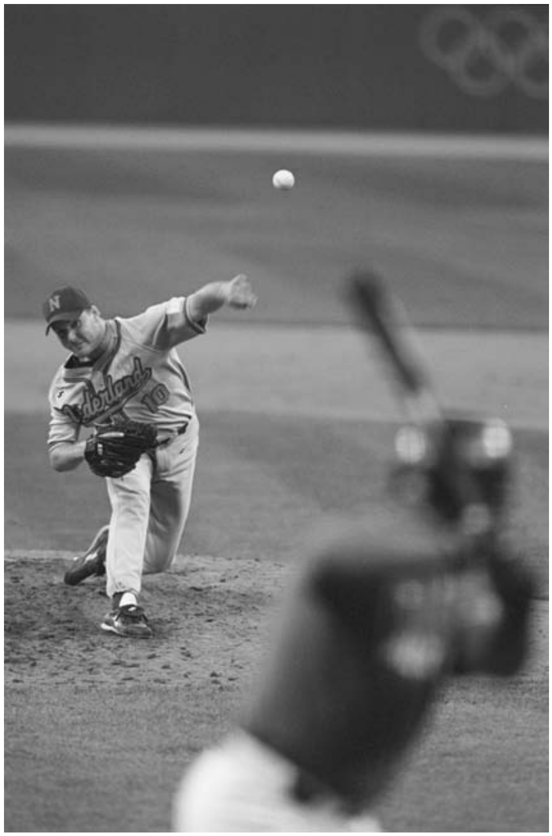

Figure 5.1 Serious injuries to baseball batters and fielders are rare, but can be catastrophic. Pitchers are far more susceptible to injury, due to overuse and sometimes poor mechanics. © IOC / Hamish BLAIR.

Table 5.2 Studies of elbow and shoulder injury in pitchers at various levels of play.

Study	Design	N	Age, in yr	Affected Joint	Frequency Measure	Percent Reporting Pain	Percent with Changes on Radiographs
Youth Leagues							
Adams (1965)	Retrospective	80	9–14	Elbow	Prevalence	45	95
Gugenheim (1976)	Retrospective	595	11–12	Elbow	Prevalence	18	28
Larson et al. (1976)	Retrospective	120	11–12	Elbow	Prevalence	18	95
Albright et al. (1978)	Prospective	54	11–12	Both	Incidence	44	
Hang et al. (2004)	Prospective	112	11–12	Elbow	Incidence	69	65
Lyman et al. (2001)	Prospective	298	9–12	Elbow	Incidence	26	
				Shoulder		32	
Lyman et al. (2002)	Prospective	488	9–14	Elbow	Incidence	28	
				Shoulder		35	
Mixed							
Torg et al. (1972)	Retrospective	49	9–18	Elbow	Prevalence	29	4
				Shoulder		29	
High School							
Grana & Rashkin (1980)	Prospective	73	15–18	Elbow	Incidence	58	56
Ochi et al. (1994)	Retrospective	130	15–18	Elbow	Prevalence	38	43
				Shoulder		38	
Collegiate							
Albright et al. (1978)	Prospective	18	18–23	Both	Incidence	61	
Professional							
Slager (1977)	Retrospective	149	Major L.	Elbow	Prevalence	61	
				Shoulder		57	
Conte et al. (2001)	Prospective	–	Major L	Elbow	% of disabled list days for all players	22[a]	
				Shoulder		28[a]	

[a] Percent reporting pain in this study is actually the percent of days on the Major League disabled list due to elbow and shoulder injuries

of male children: pitchers, baseball players who did not pitch, and healthy boys who did not play baseball (Adams 1965). The defining characteristic of injury in this study was self-reported pain, which was highest in the boys who were pitchers. Further studies have found a prevalence of elbow pain in youth and high-school pitchers between 18% and 29%, respectively, and an incidence of pain of 26% in youth and 58% in high-school pitchers. As shown in Table 5.2, shoulder pain has had less attention from the scientific community, with a prevalence of 29% (Torg et al. 1972) and an incidence of 32% to 35% (Lyman et al. 2001, 2002).

Perhaps the best estimates available for the true incidence of youth pitching injuries were completed by Lyman et al. in 2001 and 2002. The studies used a prospective design in which each pitcher was interviewed after each game, rather than at the end of a tournament or season. This was done in an effort to minimize recall bias. Again, pain was used as the defining characteristic of injury, and the study showed self-reported elbow pain of more than 25% in youth pitchers and self-reported shoulder pain of more than 30% in youth pitchers (Lyman et al. 2001, 2002).

Very few studies exist that specifically examine the injuries of pitchers at elite levels of play. Albright et al. (1978) studied 18 collegiate and 55 Little League pitchers in 1973. They found symptoms related to both elbow and shoulder injury (comprised of objective findings such as swelling and limited range of motion) in 61% of the collegiate pitchers and 44%

of the Little League pitchers. A 1977 study sent a questionnaire to every professional baseball player during the 1975 spring training season. Based on 149 pitchers' responses, an incidence rate of self-reported elbow soreness of 61% and self-reported shoulder soreness of 57% were found in professional pitchers (Slager 1977).

Where Does Injury Occur?

Anatomical Location

Recognition of commonly injured anatomical sites is essential because it alerts sports medicine professionals to areas in need of special attention. A percentage comparison of injury location reported in youth, high-school, collegiate, and professional baseball players is shown in Table 5.3. A vast majority of injuries in baseball affect either the upper or the lower extremities, with the shoulder being one of the most injured anatomical locations in baseball.

Upper Extremity

Injuries to the upper extremity are commonplace in both pitchers and position players (Lyman & Fleisig 2005). Injuries to the upper extremity can occur as a result of both overuse and an acute traumatic incident. However, the injury mechanism of a majority of these injuries is overuse. Studies have found that upper-extremity injuries comprise approximately 31.7% to 60.1% of all injuries (Table 5.3.) Between 1999 and 2003, 73% of all players placed on the disabled list (DL) in Major League baseball had injuries classified as wear and tear or as caused by overuse or insufficient rest (Redbook 2003).

The best data source for injuries (including those to the upper extremity) in Major League Baseball is the Redbook. It is an analysis of all professional baseball players and their associated time on the Major League Disabled List (DL). Shoulder and elbow injuries account for more than half (53%) of all underlying causes for Major League Baseball players to be placed on the disabled list (Redbook 2003; Conte et al. 2001). The incidence of elbow and shoulder injury in youth baseball athletes is estimated to be 26 to 35 per 100 pitchers per season (Lyman et al. 2001, 2002). These youth studies have focused primarily on a definition of injury as "pain" in the elbow or shoulder. While pain in the elbow or shoulder does not necessarily represent a medical problem, it does cause discomfort and may be an early indicator of a developing overuse injury (Lyman & Fleisig 2005).

Lower Extremity

Lower-extremity injuries are relatively uncommon in youth baseball players, but become more common as age increases and the level of play becomes more competitive (Lyman & Fleisig 2005). Injuries to the lower extremity ranged from 22.9% to 28.6% of total injuries for youth baseball players and 37.5% for high-school players. Similarly, intercollegiate and professional baseball players were generally in the range of 32.0% to 67.3% of total injuries. Ankle and knee injuries are more frequent at higher ages and skill levels as a result of sliding (Janda et al. 1988).

Head, Face, and Torso

Although they represent a small proportion of the injuries involved in baseball, injuries to the head, face, and torso often result in some of the most severe outcomes seen in baseball. Injuries to these areas can include fractures, concussions, traumatic brain injuries, and sudden death (Marshall et al. 2003). Further discussion of traumatic brain injuries and sudden death (*commotio cordis*) appears in the "Catastrophic Injury" section of this chapter.

The face and eye are particularly vulnerable and prone to penetration by fast-moving objects, such as baseballs. In a study by Napier et al. (1996), baseball was found to be the 10th leading cause of consumer product–related eye injuries in the United States and the underlying cause of most sports-related eye injuries in the United States. Marshall et al. (2003) reported a risk of facial injury in youths of 4.1 per 100,000 player-seasons based on insurance claims.

It is not surprising that an inordinate number of baseball injuries involve younger athletes. This is because of the higher participation rates of children versus adults. Vinger et al. (1999) showed that 45% of eye injuries involved youths 5 to 14 years of age. It was also observed that a majority of these eye injuries resulted from direct contact with the ball (Napier et al. 1996). Youth baseball teams can expect 2.3 ball and player impacts per game, with 7.3% causing major or extreme discomfort (Seefeldt et al. 1993).

Table 5.3 Comparison of injury location and level of play in baseball by percent of occurrence.

Study	No. of Injuries	Head/Spine/Trunk (% of Injuries)							Upper Extremity (% of Injuries)						
		Head	Face	Neck	Back	Ribs	Stomach	Total	Shoulder	Arm	Elbow	Forearm	Wrist	Hand/Finger	Total
Youth Baseball															
Pasternack et al. (1996)	66	4.5	27.2	0	1.5	0	0	**32.3**	3.0	0	4.5	7.5	0	21.2	**36.2**
Zarincznyj et al. (1980)	154	38.0	0	0	0	0	0	**38.0**	0.6	0.6	5.2	3.2	3.2	19.5	**32.3**
Cheng et al. (2000)	76	37.0	—	—	3.0[a]	—	—	**40.0**	—	—	—	—	—	—	**32.0**
High-School Baseball															
Powell and Barber-Foss (2000)	861	0	8.9	1.9	5.4[a]	0	0	**18.1**	19.7	0	0	24.6	0	0	**44.3**
Collegiate Baseball															
Whiteside (1980)	133	8.8	1.0			1.0[d]		**10.8**	21.5[b]			28.0[c]			**49.5**
Clarke and Buckley (1980)	—	—	—	—	—	—	—	**2.0**	—	—	—	—	—	—	—
Splain and Rolnick (1984)	63	0	0	0	7.9	0	0	**7.9**	12.7	6.3	6.3	0	4.8	1.6	**31.7**
McFarland and Wasik (1998)	277	4.0	0	3.0	10.0	0	0	**17.0**	24.0	6.0	12.0	9.0	0	0	**51.0**
Adult Amateur Baseball															
Lebrun et al. (1986)	33	—	3.0[g]	3.0	—	—	—	**6.0**	—	60.1	—	—	—	—	**60.1**
Professional/Olympic Baseball															
Garfinkel et al. (1981)	382	2.8[j]	2.1	4.2	0	1.8[I]	0.8	**11.7**	13.9	4.7	6.5	3.7	2.9	11.2	**42.9**
Chambless et al. (2000)	942	7.1	0	0	8.2	2.1	0	**17.4**	24.0	0	12.6	19.0	0	0	**55.6**
Junge et al. (2006)	16	0	0	0	0	0	0	**0**	6.0	25.0	13.0	0	0	13.0	**57.0**
Conte et al. (2001)	% of DL days	0	0	0	5.0	0	0	**5.0**	27.8	0	22.0	0	0	6.1	**55.9**

DL = disabled list.
[a] Unspecified spine/trunk.
[b] Shoulder and arm combined.
[c] Forearm and hand combined.
[d] Injuries classified under "torso."
[e] Hip and leg combined.

When Does Injury Occur?

Injury Onset

Injuries in baseball fall into two categories: acute/traumatic injuries and overuse injuries (typically seen in pitchers). In general, injuries are thought to occur in direct proportion to the intensity of the competition and age of the athletes (Walk et al. 1996). Injuries to fielders, batters, and base runners tend to have acute or traumatic injury mechanisms, or both, typically due to contact with the ball, the bat, another player, the ground, a base, or a fence or wall (Hale 1979). In comparison, pitching injuries tend to be the result of cumulative microtrauma because of the repetitive throwing motion (Andrews & Fleisig 1998; Yen & Metzl 2000).

No. of Injuries	Lower Extremity							
	Pelvis/Hips	Thigh	Knee	Leg	Ankle	Heel/ Achilles	Foot/Toe	Total
66	1.5	0	13.6	4.5	9.0	0	0	**28.6**
154	1.2	0	9.0	0.6	9.0	0	3.1	**22.9**
76	—	—	—	—	—	—	—	**26.0**
861	14.5	—	10.5	—	12.5	—	—	**37.5**
133	7.8[e]	—	16	—	16	—	—	**39.8**
—	37.0	—	7.0	—	—	—	—	**44.0**
63	6.4[f]	14.3	20.6	3.2	14.2	0	1.3	**60.3**
277	0	13.0	4.0	8.0	4.0	0	3.0	**32.0**
33	—	—	6.1	9.1[h]	—	—	—	**15.2**
382	3.7	6.8	12.0	6.8	2.4	2.9	7.6	**42.2**
942	14.0	0	8.5	3.1	12.6	0	0	**38.2**
16	6.0	6.0	0	19.0	6.0	0	6.0	**43.0**
% of DL days	0	0	7.3	0	0	0	0	**67.3**

[f] Groin injuries (4.8%) included.
[g] Neck and back combined.
[h] Leg and ankle combined.
[i] Refers to chest injuries.
[j] Unspecified head (1.0%), ear (1.0%), and throat (0.8%) injuries combined.

Injury rates have been reported to be four times higher during games than during practice for youth players (Radelet et al. 2002) and three times higher during games than during practice in minor league players (5.78 and 1.85 per 1,000 athlete exposures, respectively) (Chambless et al. 2000). Of 277 orthopedic problems observed by McFarland and Wasik (1998), 54% occurred during game play as opposed to 46% during practice. McFarland and Wasik (1998) also reported the injury rate during preseason practice was twice as high as during the regular season (2.97 and 1.58 per 1,000 AEs, respectively). This is most likely due to the high intensity of preseason practice and lack of physical conditioning that has accumulated during the off-season.

Table 5.4 Comparison of injury types in baseball by percent of total injuries.

Level	No. of Subjects	No. of Injuries	Abrasions	Concussions	Fractures	Inflamations	Laceration	Strain	Nonspecific	Other 1	Other 2	Other 3	Sprain
Youth													
Hale (1961)	771,810	15,444	52.0[a]	3.0	19.0		10.0			3.0[b]			13.0
Heald (1991)	5,000,000	96,000	43.0[a]	2.0	19.0		10.0			5.0[b]	3.0[c]		18.0[d]
Cheng at al. (2000)[e]	—	76	20.0		24.0[f]		17.0	32.0[d]		7.0[g]			
High School													
Lowe et al. (1987)	256	3			33.3		33.3						33.3
Powell & Barber-Foss (2000)	2,167	861			8.8			31.2	0.3	1.7[h]	30.7[i]	6.6[j]	20.6
Collegiate													
Clarke & Buckley (1980)	—	—			10.0[k]			28.0		1.0[h]	5.0[l]	19.0[c]	37.0
Whiteside (1980)		133			3.4			26.1		6.7[h]	29.4[i]		34.5
Professional													
Garfinkel et al. (1981)	—	382	16.7	0.5	0.5	11.6[m]	2.8	17.8	42.2[a]	0.5[m]	0.6[o]	0.4[p]	5.5
Martin et al. (1987)	148	8	25.0					37.5	12.5	12.5[h]			12.5
Junge et al. (2006)	—	16	57.0[q]						19.0	19.0			19.0

[a] Includes contusions.
[b] Dental injuries.
[c] Other unspecified injuries.
[d] Includes sprains.
[e] Includes softball data.
[f] Includes dislocations.
[g] Intracranial injuries.
[h] Neurotrauma.
[i] General trauma.
[j] Musculoskeletal injuries.
[k] Combines dental fractures with other types of fractures.
[l] Chronic orthopedic.
[m] Combines blisters (4.9), epicondylitis/tendinitis (4.1), rotator cuff tendinitis (1.6), bursitis (0.2), myositis (0.2), myositis ossificans (0.2), synovitis (0.2), and paronychia (0.2).
[n] Foreign body.
[o] Combines effusion (0.2), fascial hernia (0.2), and thigh atrophy (0.2).
[p] Combines nail avulsion and corns.
[q] Includes contusions and lacerations.

What Is the Outcome?

Injury Type

Information from studies reporting distribution of injuries by injury type is summarized in Table 5.4. A majority of baseball-related injuries for levels from youth to professionals are not severe. Abrasions, followed by fractures, sprains/strains, and lacerations are the most common injury types (Walk et al. 1996). The incidence of injuries, by type, provides a clear pattern of occurrences for athletes at the youth, high-school, collegiate, and professional levels.

Time Loss

A commonly used measure of injury severity is the duration of time an injured athlete is kept from participating in their sport. Not all injuries in baseball result in time loss. Those that do, however, can keep an athlete out from just a few days to several months. A study of the 2004 Greece Olympic Games found that 44% of injuries resulted in time loss (Junge et al. 2006). Garfinkel et al. (1981) reported that 94% of professional athletes suffered injuries that prevented their participation for <8 days, 5% missed 8 to 28 days of activity, and 1% did not participate in activity for >28 days. In Major League Baseball, there were an average of 371 players with 443 injuries per year between 1999 and 2003, which resulted in a total of 24,463 disability days during this 5-year span (Redbook 2003). In addition, each Major League team averaged 12 players on the DL, for a total of 815 days, per season. During the same 5-year period, the average number of days spent on the DL per injury was 66, an increase of 24% from the previous 5-year period (Redbook 2003). Approximately one third of all injured players on the DL miss ≤30 days, one third miss 31 to 90 days, and one third miss >91 days. In addition, Chambless et al. (2000) reported that higher-level professional athletes (AAA, AA, A) were out 1 to 3 days, while rookies were out 4 to 20 days per injury. These results suggest that athletes playing professional baseball for the first time are not in the best physical shape at the beginning of their careers and perform above their physical capabilities to be successful at the professional level.

Sometimes, players miss time, but are not put on the disabled list. During the 2002 and 2003 seasons, players in this category included 410 players and 2495 missed days. These missed days ranged from a low of 23 days to a high of 163 (Redbook 2003).

Studies have reported that 25% of collegiate baseball injuries result in the loss of ≤10 days (Dick et al. 2007). Similarly, after following a baseball team for three seasons, McFarland and Wasik (1998) found that injured players usually missed <1 week or >21 days.

Time lost from practice or games has been evaluated in only two studies of high school and youth baseball. However, as compared with higher levels of play, similar results were found when studying youth players. In 1978, Garrick and Requa found that 27% of those injured in youth baseball missed at least 5 days of practice or games. Powell and Barber-Foss (1999) reported on the median time lost due to mild traumatic brain injury in youth baseball players. They found the median time missed was 3 days and no time loss was more than 3 weeks. Time lost to injuries requires further study, especially in conjunction with the specific type of injury at specific levels of play (Walk et al. 1996).

Clinical Outcome

Studies of long-term clinical outcomes for baseball-related injuries are severely lacking. Francis et al. (1978) reported that 15% of 398 college students who pitched as youth pitchers felt that their ability to throw in college was hindered by pain, tenderness, or limitation of movement as a result of their youth pitching. This study suggests that a potential for disability exists that is associated with youth baseball pitching and continues into adulthood. No similar study of the long-term effects of baseball participation has been conducted. In 1999, the American Sports Medicine Institute began a 10-year prospective study attempting to identify long-term effects of baseball pitching on youth pitchers. Each of the 476 youth pitchers in the study were identified and contacted every year. Four-year preliminary findings showed no significant relationship between number of innings pitched, position played, types of pitches, years pitched, and whether the athlete missed any games and whether the athlete reported chronic arm pain (Childress 2003). However, analysis of the entire 10-year follow up will be needed in order to make any final conclusions.

Catastrophic Injury

Although rare, catastrophic injuries in baseball need to be identified and studied. A *catastrophic injury* was defined as a "sport injury that resulted in a brain or spinal cord injury or skull or spinal fracture" and a *direct injury* as an one that "resulted directly from participation in the skills of the sport" (Mueller 2007). A study by Nicholls et al. (2004) noted that softball and baseball are responsible for the highest sporting fatality rate among 5-to-14-year-olds in the United States–88 deaths from 1973 through 1995.

The most common cause of fatality as a result of playing baseball is *commotio cordis* (Lyman & Fleisig 2005). In clinical terms, *commotio cordis* is cardiac arrest as a result of a blunt, nonpenetrating, and usually innocent-appearing chest blow (Maron et al. 2002). Maron et al.'s 2002 study found that 53 of 128 *commotio cordis* events, entered into the U.S. *Commotio Cordis* Registry, were caused by chest blows from baseballs. Baseball has the lowest risk of traumatic brain injuries in high-school athletes, 0.05 traumatic brain injury per 1,000 athlete exposures (Powell and Barber-Foss 1999). Spinal and severe head injuries have also been noted, but are much less common than in contact sports such as football and hockey (Powell and Barber-Foss 1999).

The number of baseball-related fatalities is lower for high-school and college players than for youth players. The National Center for Catastrophic Sport Injury Research reports that between the fall of 1982 and the fall of 2006 there were nine reported fatalities among high-school baseball players and three among collegiate baseball players (Mueller 2007).

Boden et al. (2004) studied the same National Center for Catastrophic Sport Injury Research data and calculated a total direct catastrophic injury rate of 1.7 per 100,000 collegiate baseball players and a fatality rate of 0.86 per 100,000 collegiate baseball players.

Economic Cost

Lost wages and lost profit are seen only in professional baseball and do not apply to youth, high-school, or college players. According to the Redbook (2003), from 1999 through 2003, Major League Baseball teams paid $1.4 billion to players on the DL, which is more than double that of the preceding 5-year period ($585 million from 1994 through 1998). It was also determined that $11.9 million were lost per team to players being on the DL in 2003. More than half of all DL days (59%) and dollars (57%) lost were due to injuries resulting in surgery. For injuries requiring surgery, a Major League team can expect a player to miss an average of 105 days and cost his team $1.3 million in lost wages (Redbook 2003).

What Are the Risk Factors?

An important aspect in the epidemiology of baseball injuries is the identification of factors that increase one's risk of being injured. However, information on these risk factors is relatively limited. Intrinsic risk factors are those associated with individuals' biologic and psychosocial characteristics that predispose a baseball player to injury. Extrinsic factors are outside influences that have an impact on the athlete while engaging in their sport – for example, the equipment used and the playing environment. Our review of the literature revealed a definite paucity of research on risk factors in baseball athletes.

Intrinsic Factors

Nonpitcher

Intrinsic risk factors for nonpitchers are very similar to those for pitchers, but have not been researched as extensively. Level of play is probably the most significant risk factor yet to be identified. As an athlete progresses to higher levels of play the risk of injury increases. Bigger, stronger, and more aggressive players tend to throw faster, hit harder, and run faster, which all lead to increases in the number of injuries (Lyman & Fleisig 2005). Higher-level athletes have a higher risk of injuring their lower extremities, mainly because poor mechanics increase the risk of injury when sliding (Janda et al. 1988).

Pitcher

Physical characteristics

Perhaps the most persuasive evidence regarding the association of injuries to intrinsic factors is related to physical characteristics of the pitcher. Younger players are more likely to suffer from injuries to the upper extremities and from being hit by pitched balls while batting (Hale 1979; Grana & Rashkin 1980). In addition, younger baseball athletes experience pain associated with the epiphyseal areas, while older players experience injuries associated with overuse that leads to ligament and tendon tears (Walk et al. 1996). Lyman et al. (2001) observed 9-to-12-year-olds and found that the risk of elbow pain was 2.9-fold greater among ⩾12-year-old pitchers as compared with those <10 years of age. Elbow pain was also increased 4.1-fold among pitchers 86 to 100 lb and 5.4-fold among pitchers over 100 lb as compared with those <71 pounds. These findings are likely due to additional secondary ossification centers in the youth elbow (Lyman & Fleisig 2005). In comparison, greater height was associated with a decreased risk of elbow pain, with pitchers ⩾61 in. having a 65% decreased risk of elbow pain as compared with those <55 in., possibly indicating skeletal maturity with fusion of the secondary ossification centers. Age was not significantly associated with a decreased risk of shoulder pain. In contrast to elbow pain, height ⩾61 in. was associated with a 3.6-fold increased risk of shoulder pain as compared with pitchers <55 in. (Lyman et al. 2001).

Pitching Motion

Biomechanical research at the American Sports Medicine Institute has found that improper pitching mechanics leads to increased kinetics (i.e., forces and torques) which is thought to be an implication for injury (Fleisig et al. 1989; Dillman et al. 1993; Fleisig 1994; Fleisig et al. 1995, 1996). However, the relationship between mechanics and injury has not yet been fully established, and no studies exist identifying mechanics as a risk factor for injury.

Albright et al. (1978) found that pitchers who threw with a sidearm motion were more likely to show symptoms of injury (presence and severity of pain, swelling, and decreased range of motion) than those pitchers who did not throw sidearm.

Self-Satisfaction

Psychology plays an important role in the self-report of injury in pitchers and should be examined more closely, particularly in the youth athlete (Lyman & Fleisig 2005). Lyman et al. (2001) asked pitchers to rate their performance in each game pitched. Results showed that the level of self-satisfaction was inversely related to the claim of experiencing arm pain. It is unknown whether this represented using pain as an excuse or as a reason for performance (Lyman et al. 2001).

Extrinsic Factors

Nonpitcher

Extrinsic factors associated with baseball injuries vary greatly based on the position played by the athlete. Factors associated with injuries to non-pitchers or position players are primarily attributed to the surrounding environment, including rigidity of the bases and protective equipment used while batting, fielding, and base running.

Fixed Bases

One risk factor that affects players while running the bases and sliding are the use of fixed bases. Fixed bases have been found to cause contusions, fractures, sprains, and ligamentous injuries to the hands, feet, and knees (Janda et al. 1988). Most studies published on base running or sliding injuries attempt to prove that breakaway bases are a safer alternative to fixed, more rigid bases, rather than simply describing the incidence/prevalence of associated injuries. These studies may have focused on breakaway bases as a safer alternative because, while poor musculoskeletal conditioning, poor technique, and late decisions to slide may be risk factors for sliding and base-running injuries (Janda et al. 2001), it is much more difficult to alter the behaviors of a player than to simply modify his or her environment (Lyman & Fleisig 2005). A simple environmental change, using breakaway bases, has proven to be an effective injury-prevention tool, and will be discussed further in the "Injury Prevention" section of this chapter.

Pitchers

Extrinsic risk factors associated with pitching injuries primarily revolve around pitch counts and types of pitches thrown by the athlete.

Pitch Counts

Two prospective longitudinal studies looked at the number of pitches thrown per game and during the season among adolescent pitchers (Lyman et al. 2001, 2002). The first found no significant associations between pitches thrown during a game and self-reported elbow pain. However, as game pitches increased, a highly significant dose–response relationship was found for self-reported shoulder pain, with a 2.5-fold increased risk of shoulder pain associated with ⩾75 pitches per game (Lyman et al. 2001). The second study using the same methods with a larger sample size, broader age range (9–14 years), and athletes from a larger geographic area found a similar association with increasing number of game pitches and risk of both elbow and shoulder pain (Lyman et al. 2002).

In comparison, the relationship between the total number of pitches thrown in a season (cumulative pitches) and risk of elbow and shoulder pain varied by study. Lyman et al., in the 2001 study, noted a 53% decreased risk of elbow injury associated with 300 to 599 pitches and a 3.4-fold increased risk of elbow injuries associated with ⩾600 pitches as compared with <300 pitches. Pitchers in this study also had a decreased risk of shoulder injury with an increased cumulative number of pitches. This contrasts with an increased risk of elbow injury associated with >200 cumulative pitches as compared with ⩽200 pitches among pitchers in the Lyman et al. 2002 study. Pitchers who threw a greater number of pitches were also found to have a decreased risk of shoulder pain (Lyman et al. 2001). The decreased risk of shoulder pain may be due to survivorship, in which pitchers who had low cumulative pitch counts were those who stopped pitching, or who reduced their pitching load to avoid shoulder pain (Lyman & Fleisig 2005).

Pitch Type

It is hypothesized that the use of the curveball by young pitchers causes increases in the forces and torques of the pitching elbow and shoulder, thereby increasing the risk of injury in this age group. Olsen et al. (2006) found that compared to healthy pitchers, youth pitchers who had elbow or shoulder surgery did not throw significantly more curveballs, nor did they start throwing the curveball earlier in life. However, Lyman et al. (2002) found an 86% increased risk of elbow pain with throwing sliders and a 52% increased risk of shoulder pain with throwing curveballs as compared with fastballs ($P<0.05$). Biomechanical research supports the findings that breaking pitches put the athlete at no more risk than fastballs (Dun et al. 2008).

Other Risk Factors

Lyman et al. (2001) identified additional risk factors in youth baseball pitchers. Weightlifting was associated with a nearly 2-fold increased risk of elbow pain. The type and frequency of the youth players' workouts were unknown; therefore, it is not a sound conclusion that weightlifting is detrimental to pitchers. Playing baseball outside of an organized league was associated with a 2.3-fold increased risk of elbow pain. This obviously increases a pitcher's pitch count beyond those recorded in the study, leading to further overuse (Lyman et al. 2002). Pitching while fatigued was the most influential factor in pitching injuries. Lyman et al. (2001) and Olsen et al. (2006) found that pitchers who continually pitched while fatigued (recorded as self-reported fatigue while pitching) were at a 6 and 36 times increased risk of being injured, respectively, as compared with those who did not pitch while fatigued.

What Are the Inciting Events?

Pitching Injuries

Pitchers have the highest probability of injury as compared with the other players (Redbook 2003).

This increased risk is due to the repetitive pitching motion, causing cumulative microtrauma to the elbow and shoulder (Lyman & Fleisig 2005). In particular, youth pitchers are at the greatest risk of injury because of their immature skeletons. The cumulative trauma that began at a young age is often the underlying cause of the severe pitching injuries seen in high-school, college, and professional pitchers (Lyman & Fleisig 2005).

Batting Injuries

Our review of the literature revealed no epidemiologic studies focused on batting-related injuries. Danis et al. (2000) examined the rate of youth batting injuries, but restricted the data to only facial injury and the effect of players wearing face shields. In an effort to describe background incidence, the study found that 5.3 per 100 athletes reported facial injury while batting.

Base-Running

Base runners experience injury due to several mechanisms: they are hit with balls both thrown in the field and hit from the batter, they experience muscular injuries while running, and they sustain contact injuries while sliding. Hosey and Puffer (2000) examined three NCAA Division I teams and found that collegiate players experience 6.01 injuries per 1,000 slides. Feet-first slides (7.31 per 1,000 slides), dive backs (5.75 per 1,000 slides), and headfirst slides (3.53 per 1,000 slides) are the three main sliding mechanics and determine which anatomical locations are injured (Hosey & Puffer 2000). The majority of research on sliding injuries has focused on the comparison of breakaway bases versus traditional bases, which will be covered later in the chapter.

Fielding

No studies on fielding injuries were available for review. However, it is believed that these injuries occur because of contact with the ball, the ground, another fielder, or a fence or wall (Hale 1979). Garfinkel et al. (1981) found an injury distribution among professional baseball players as follows: pitcher, 14.6%; catcher, 13.3%; first base, 1.8%; second base, 7.6%; third base, 3.4%; shortstop, 2.6%; outfielders, 9.8%; runner, 21.7%; batters, 23.8%; and miscellaneous injuries, 1.1%. The issue of studying injuries in baseball by position has received little attention and clearly is a topic for future research.

Injury Prevention

Nearly all injury-prevention studies are of the youth and high-school level. Perhaps this is an effort to instill safe play practices at a young age that can be maintained by athletes as they mature and advance in their baseball careers. Our review of the literature revealed a great paucity of injury-prevention studies in baseball. The few studies that have been completed have examined injury-prevention tools for baseball players including, equipment and behavioral changes. As previously mentioned it is much easier to modify one's environment rather than a behavior; hence, a majority of injury prevention is done through equipment.

Equipment

Face Guards/Face Shields

Although batting helmets have been mandatory in Major League Baseball since the 1957–1958 season (Light 1996; Morris 2006; Major League 2007), they have not been rigorously tested for their effectiveness. A somewhat new and effective addition to batting helmets is face guards. Research has found that the use of face guards while batting reduces the risk of eye and facial injuries (Lyman & Fleisig 2005). In a nonrandomized study of facial injuries in youth leagues, Marshall et al. (2003) found a 35% reduced risk of facial injury in leagues using face shields as compared with those not using the shields. The argument against the use of face shields in higher levels of baseball is that the ability to see high-velocity pitches and breaking pitches effectively can be compromised. The use of face guards decreases with an increase in level of competition (Marshall et al. 2003) and should be an area of future improvement in baseball injury prevention. However, using protective equipment alone may not be the answer to injury prevention, as the proportion of injuries prevented would be less than 32% (Kyle 1996).

Safety Baseballs

By reducing the hardness of the baseball, researchers hope to lower the frequency of contusions, fracture, and most importantly, *commotio cordis* (Yamamoto et al. 2001; Marshall et al. 2003). Laboratory studies have shown that baseballs with a lower mass and less stiffness have a reduced potential for injury (Vinger et al. 1999; Yamamoto et al. 2001). In a nonrandomized study, Marshall et al. (2003) found that safety baseballs exhibited an overall decreased risk of injury of 23% as compared with regular hard baseballs.

Because of the deformity characteristics, softer balls may penetrate the eye socket more deeply, causing more severe eye injuries. Therefore, the softest baseballs should be used only in very young athletes, for whom the speed of a pitched, thrown, or batted ball is markedly slower (Vinger et al. 1999).

Breakaway Bases

Improper technique may be the strongest risk factor for sliding injuries; however, altering an athlete's behavior is difficult. A simple and inexpensive solution is the use of breakaway bases. Studies have shown that the utilization of breakaway bases has the potential to prevent up to 96% of sliding injuries, minimizing the occurrence of fractures, sprains, and strains (Janda et al. 1988). Sendre et al. (1994) studied breakaway bases and showed the injury rate, in a nonrandomized study, among college, high-school, and youth baseball and softball players was 0.03 per 1,000 AEs, as compared with 1.0 per 1,000 AEs with standard stationary bases. Similarly, injury rates using breakaway bases in the NCAA was 0.41 per 100 games, as compared with 2.01 per 100 games for fixed bases (Dick et al. 2007). The possibility of injury prevention by using breakaway bases is indisputable, and these should be used at all levels of play (Sendre et al. 1994).

Further Research

Currently the definition of both "injury" and "exposure" are the largest obstacles to overcome in sports-injury-prevention research in general and in baseball injury research in particular (Lyman 2005). Our review of the literature found studies using a variety of definitions of "injury." These definitions ranged from self-reported pain, to injuries requiring missed games or practice, to injuries requiring surgery, to emergency department visits, to insurance claims. Each one of these definitions encompasses a completely different collection of data, making them impossible to compare with each other. Therefore, a clear and consistent definition of injury is needed to improve and better understand baseball injuries and their underlying characteristics. Perhaps time missed from games and/or practice would be the best measure of injury for both pitchers and nonpitchers.

Furthermore, "exposure" was found to be defined in a variety of ways, from counting players, to counting games or practices, to counting pitches. Most current sports injury surveillance systems use a measure of athlete exposures. This definition of exposure is best, and allows for future studies to be easily compared with previous studies. However, athlete-exposures work well for nonpitchers, but not for pitchers. Starting pitchers and relief pitchers have dramatically different levels of exposure throughout a game or season. Therefore, the number of innings pitched, batters faced, or pitches thrown would be the best measure of exposure for pitchers (Lyman et al. 2005).

Because of the paucity of risk-factor studies, particularly among elite baseball athletes, additional factors should be studied including muscle strength, flexibility, ball hardness, and training regimens.

The effectiveness of protective equipment such as face guards, safety baseballs, and breakaways bases has been proven in numerous studies. Further research should focus on redesigning this equipment to make it more player-friendly to increase its widespread use and acceptability by players, coaches, and fans, while still providing protection to the athlete. The effectiveness of several other types of protective equipment has not been proven. The development of the modern-day double-ear-flap batting helmet by Creighton Hale, Ph.D., has not been studied for its effectiveness in the prevention of head injuries. Lightweight baseballs have been studied as an injury-prevention strategy. Fleisig et al. (2006) showed that throwing lightweight baseballs reduced shoulder and elbow loads in youth pitchers. Decreased loads are thought to lead to fewer injuries in baseball pitching, although additional studies are needed to document a reduction of injuries with this type of baseball.

Studies are needed to evaluate other potential injury-prevention strategies such as proper pitching technique and pitch limits. It has been determined that throwing and pitching using improper mechanics produces more force and torque on the elbow and shoulder (Fleisig 1994; Fleisig et al. 1995, 1996). Future randomized, controlled trials comparing training pitchers in the use of proper technique are needed to prove effectiveness in reducing injuries. No prevention studies on pitching limits exist yet. Based on studies such as those by Lyman et al. in 2001 and 2002 (described in the "What Are the Risk Factors" section of this chapter), Little League Baseball has changed from limits on the number of innings pitched to limits on pitches per game. Research on the success of these pitch-count limits is in progress. The challenge for researchers, baseball organizations, and individuals is to prevent pitchers from pitching so much that they develop overuse injuries but also allow pitchers to pitch enough to develop strength, technique, and experience. With the implementation of new pitch-count rules in Little League Baseball, it should be of the utmost priority to study their effects on the injury rates in youth baseball. Similarly, the effects of pitch counts at the high-school and college levels should be studied to determine whether pitch count rules should be implemented at those levels.

References

Adams, J. (1965) Injury to the throwing arm: a study of traumatic changes in the elbow joints of boy baseball players. *California State Journal of Medicine* **102**, 127–132.

Albright, J., Jokl, P., Shaw, R. & Albright, J. (1978) Clinical study of baseball pitchers: correlation of injury to the throwing arm with method of delivery. *American Journal of Sports Medicine* **6**(1), 15–21.

Andrews, J. & Fleisig, G. (1998) Preventing throwing injuries. *Journal of Orthopaedic & Sports Physical Therapy* **27**, 187–188.

Boden, P., Tacchetti, R. & Mueller F., (2004) Catastrophic injuries in high school and college baseball players. *American Journal of Sports Medicine* **32**(5), 1189–1196.

Burt, C. & Overpeck, M. (2000) Emergency visits for sports-related injuries. *Annals of Emergency Medicine* **37**(3), 301–308.

Chambers, R. (1979) Orthopaedic injuries in athletes (ages 6 to 17). *American Journal of Sports Medicine* **7**(3), 195–197.

Chambless, K., Knudtson, J., Eck, J. & Covington, L. (2000) Rate of injury in minor league baseball by level of play. *The American Journal of Orthopedics*, **29,** 869–872.

Cheng, T., Fields, C., Brenner, R., Wright, J., Lomax, T. & Scheidt, P. (2000) Sports injuries: an important cause of morbidity in urban youth. *Pediatrics* **105**(3), 1–6.

Childress, R. (2003) *Elbow and Shoulder Pain in Youth Baseball Players.* Thesis, University of Alabama, Birmingham, AL.

Clarke, K. & Buckley, W. (1980) Women's injuries in collegiate sports. *American Journal of Sports Medicine* **8**(3), 187–191.

Committee on Sports Medicine and Fitness. (2001) Risk of injury from baseball and softball in children. *Pediatrics* **107**(4), 782–784.

Conn, J., Annest, J. & Gilchrist, J. (2003) Sports and recreation related injury episodes in the US population, 1997–99. *Injury Prevention* **9**, 117–123.

Conte, S., Requa, R. & Garrick, J. (2001) Disability days in Major League baseball. *American Journal of Sports Medicine* **29**(4), 431–436.

Danis, R., Hu, K. & Bell, M. (2000) Acceptability of baseball face guards and reduction of oculofacial injury in receptive youth league players. *Injury Prevention* **6**, 232–234.

Dick, R., Sauers, E., Agel, J., Keuter, G., Marshall, S., McCarty, K. & McFarland, E. (2007) Descriptive epidemiology of collegiate men's baseball injuries: national collegiate athletic association injury surveillance system, 1988–1989 through 2003–2004. *Journal of Athletic Training* **42**(2), 183–193.

Dillman, C., Fleisig, G. & Andrews, F. (1993) Biomechanics of pitching with emphasis upon shoulder kinematics. *Journal of Orthopaedic & Sports Physical Therapy* **18**(2), 402–408.

Duda, M. (1987) News briefs: NCAA survey shows injury trends. *The Physician and Sports Medicine* **15**(2), 30.

Dun, S., Loftice, J., Fleisig, G., Kingsley, D. & Andrews, J. (2008) A biomechanical comparison of youth baseball pitches: is the curveball too stressful? *American Journal of Sports Medicine* **36,** 686–692.

DuRant, R., Pendergrast, R., Seymore, C., Gaillard, G. & Donner, J. (1992) Findings from the preparticipation athletic examination and athletic injuries. *American Journal of Diseases of Children* **146**, 85–91.

Fleisig, G. (1994) *The Biomechanics of Baseball Pitching.* Thesis, University of Alabama, Birmingham, AL.

Fleisig, G., Andrews, J., Dillman, C. & Escamilla, R. (1995) Kinetics of baseball pitching with implications about injury mechanisms. *American Journal of Sports Medicine* **23**(2), 233–239.

Fleisig, G., Barrentine, S., Escamilla, R. & Andrews, J. (1996) Biomechanics of overhand throwing with implications for injuries. *Sports Medicine* **21**(6), 421–437.

Fleisig, G., Barrentine, S., Zheng, N., Escamilla, R. & Andrews, J. (1999) Kinematic and kinetic comparison of baseball pitching among various levels of development. *Journal of Biomechanics* **32**, 1371–1375.

Fleisig, G., Dillman, C. & Andrews, J. (1989) Proper mechanics for baseball pitching. *Clinical Sports Medicine* **1**, 151–170.

Fleisig, G., Phillips, R., Shatley, A., Loftice, J., Dun, S., Drake, S., Farris, J. & Andrews, J. (2006) Kinematics and kinetics of youth baseball pitching with standard and lightweight balls. *Sports Engineering* **9**, 155–163.

Francis, R., Bunch, T. & Chandler, B. (1978) Little league elbow: a decade later. *The Physician and Sports Medicine* **6**, 88–94.

Garfinkel, D., Addison, A., Talbot, A., Clarizio, M. & Young, R. (1981) Medical problems on a professional baseball team. *The Physician and Sports Medicine* **9**(7), 85–93.

Garrick, J. & Requa, R. (1978) Injuries in high school sports. *Pediatrics* **61**(3), 465–469.

Grana, W. (1979) Summary of 1978–79 injury registry for Oklahoma secondary schools. *Journal of the Oklahoma State Medical Association* **72**(10), 369–372.

Grana, W. & Rashkin, A. (1980) Pitcher's elbow in adolescents. *American Journal of Sports Medicine* **8**(5), 333–336.

Gugenheim, J., Stanley, R., Woods, G. & Tullos, H. (1976) Little League survey: the Houston study. *American Journal of Sports Medicine* **4**(5), 189–200.

Hale, C. (1961) Injuries among 771,810 little league baseball players. *The Journal of Sports Medicine and Physical Fitness* **1**(2), 80–83.

Hale, C. (1979) Protective equipment for baseball. *The Physician and Sports Medicine* **7**(7), 58–63.

Hang, D., Chao, C. & Hang, Y. (2004) A clinical and roentgenographic study of little league elbow. *American Journal of Sports Medicine* **32**(1), 79–84.

Heald, J. (1991) *Summary of baseball/softball injuries* Worth Sports Company, Tullahoma, TN.

Hosey, R. & Puffer, J. (2000) Baseball and softball sliding injuries: incidence, and the effect of technique in collegiate baseball and softball players. *American Journal of Sports Medicine* **28**(3), 360–363.

Hutchinson, M. & Ireland, M. (2003) Overuse and throwing injuries in the skeletally immature athlete. *American Academy of Orthopaedic Surgeons Instructional Course Lecture* **52**, 25–36.

Junge, A., Langevoort, G., Pipe, A., Peytavin, A., Wong, F., Mountjoy, M., Beltrami, G., Terrell, R., Holzgraefe, M., Charles, R. & Dvorak, J. (2006) Injuries in team sport tournaments during the 2004 Olympic games. *American Journal of Sports Medicine* **34(4)**, 565–576.

Janda, D., Bir, C. & Kedroske, B. (2001) A comparison of standard vs. breakaway bases: an analysis of a preventative intervention for softball and baseball foot and ankle injuries. *Foot & Ankle International* **22**(10), 810–816.

Janda, D., Wojtys, E., Hankin, F. & Benedict, M. (1988) Softball sliding injuries: a prospective study comparing standard and modified bases. *Journal of the American Medical Association* **259**, 1848–1850.

Kyle, S. (1996) *Youth Baseball Protective Equipment Project: Final Report,* U.S. Consumer Product Safety Commission, Washington, DC:

Larson, R., Singer, K., Bergstrom R. & Thomas, S. (1976) Little League survey: the Eugene study. *American Journal of Sports Medicine* **4**(5), 201–210.

Lebrun, C., Morrell, R. & Sutherland, C. (1986) Organizing sports medicine coverage at the Canada summer games. *The Physician and Sports Medicine* **14**(11), 118–127.

Light, J. (1997) *The Cultural History of Baseball.* McFarland & Company, Jefferson, NC.

Link, M., Maron, B., Wang, P., Pandian, N., VanderBrink, B. & Estes, N. 3rd. (2002) Reduced risk of sudden death from chest wall blows (commotio cordis) with safety baseballs. *Pediatrics* **109**(5), 873–877.

Lowe, E., Perkins, E. & Herndon, J. (1987) Rhode Island high school athletic injuries 1985–1986. *Rhode Island Medical Journal* **70**, 265–270.

Lyman, S., Fleisig, G., Andrews, J. & Osinski, E. (2002) Effect of pitch type, pitch count, and pitching mechanics on risk of elbow and shoulder pain in youth baseball pitchers. *American Journal of Sports Medicine* **30(4)**, 463–468.

Lyman, S., Fleisig, G., Waterbor, J., Funkhouser, E., Pulley, L., Andrews, J., Osinski, D. & Roseman, J. (2001) Longitudinal study of elbow and shoulder pain in youth baseball pitchers. *Medicine & Science in Sports & Exercise* **33**(11), 1803–1810.

Lyman, S. & Fleisig, G. (2005) Baseball injuries. In: *Epidemiology of Pediatric Sports Injuries: Team Sports* (Maffulli, N. & Caine, D.J., eds.), Medicine and Sport Science, pp. 9–30.

Major League Baseball Official Rule Book. (2007) The Official Site of Major League Baseball. URLhttp://mlb.mlb.com/mlb/official_info/official_rules/foreword.jsp [accessed on November 1, 2007]

Maron, B.J., Gohman, T.E., Kyle S.B., Estes N.A. 3rd & Link, M.S. (2002) Clinical profile and spectrum of commotio cordis. *Journal of the American Medical Association* **287**(9), 1142–1146.

Marshall, S., Mueller F., Kirby, D. & Yang, J. (2003) Evaluation of safety balls and faceguards for prevention of injuries in youth baseball. *Journal of the American Medical Association* **289**(5), 568–574.

Martin, R., Yesalis, C., Foster, D. & Albright, J. (1987) Sports injuries at the 1985 Junior Olympics: an epidemiological analysis. *American Journal of Sports Medicine* **15**(6), 603–608.

McFarland, E. & Wasik, M. (1998) Epidemiology of collegiate baseball injuries. *Clinical Journal of Sport Medicine* **8**(1), 10–13.

McLain, L. & Reynolds, S. (1989) Sports injuries in a high school. *Pediatrics* **84**(3), 446–450.

Morris, P. (2006) *A Game of Inches: The Stories behind the Innovations That Shaped Baseball*. Ivan R. Dee, Chicago, IL.

Mueller, F. (2007) National Center for Catastrophic Sport Injury Research. URL http://www.unc.edu/depts/nccsi [accessed on September 25, 2007]

Napier, S., Baker, R., Sanford, D. & Easterbrook, M. (1996) Eye injuries in athletics and recreation. *Survey of Ophthalmology* **41(3)**, 229–244.

Nicholls, R., Elliott, B. & Miller, K. (2004) Impact injuries in baseball. *Sports Medicine* **34**(1), 17–25.

Oberlander, M., Chisar, M. & Campbell, B. (2000) Epidemiology of shoulder injuries in throwing overhead athletes. *Sports Medicine and Arthroscopy Review* **8**, 115–123.

Ochi, T., Shimaoka, Y. & Nakagawa, S. (1994) Enactment of a provision for restricting pitching in national high school championship games. *Clinical Sports Medicine* **11**, 851–853.

Olsen, S., Fleisig, G., Dun, S., Loftice, J. & Andrews, J. (2006) Risk factors for shoulder and elbow injuries in adolescent baseball pitchers. *American Journal of Sports Medicine* **34**(6), 905–912.

Olympic Movement, Official Website of the Olympic Movement. URL http://www.olympic.org/uk/sports/programme/index_ uk.asp?SportCode=BB [accessed on September 7, 2007]

Pasternack, J., Veenema, K. & Callahan, C. (1996) Baseball injuries: a little league survey. *Pediatrics* **98**(3), 445–448.

Powell, J. & Barber-Foss, K. (2000) Sex-related injury patterns among selected high school sports. *American Journal of Sports Medicine* **28**(3), 385–391.

Powell, J. & Barber-Foss, K. (1999) Traumatic brain injury in high school athletes. *Journal of the American Medical Association* **282**(10), 958–963.

Radelet, M., Lephart, S., Rubinstein, E. & Myers, J. (2002) Survey of the injury rate for children in community sports. *Pediatrics* **110**, e28.

Redbook (2003) *Major League Baseball Player Disability Analysis,* American Specialty Companies, Inc., Roanoke, IN.

Seefeldt, V., Brown, E., Wilson, D., Anderson D., Walk, S. & Wisner, D. (1993) *Influence of Low-Compression versus Traditional Baseballs on Injuries in Youth Baseball,* Institute for the Study of Youth Sports, Michigan State University, East Lansing, MI, pp. 1–31.

Sendre, R., Keating, T., Hornak, J. & Newitt, P. (1994) Use of the Hollywood impact base and standard stationary base to reduce sliding and base-running injuries in baseball and softball. *American Journal of Sports Medicine* **22(4)**, 450–453.

Slager, R. (1977) From little league to big league, the weak spot is the arm. *American Journal of Sports Medicine* **5**(2), 37–48.

Splain, S. & Rolnick, A. (1984) Sports injuries at a nonscholarship university. *The Physician and Sports Medicine* **12**(7), 55–60.

Torg, J., Pollack, H. & Sweterlitsch, P. (1972) The effect of competitive pitching on the shoulder. *Pediatrics* **49**(2), 267–272.

Vinger, P. (1981) The incidence of eye injuries in sports. *International Ophthalmology Clinics* **21**(4), 21–46.

Vinger, P., Duma, S. & Crandall, J. (1999) Baseball hardness as a risk factor for eye injuries. *Archives of Ophthalmology* **117**, 354–358.

Walk, S., Clark, M. & Seefeldt, V. (1996) Baseball and softball. In: *Epidemiology of Sports Injuries,*(Caine, D.J., Caine, C.G., & Lindner, K.J., eds.), Human Kinetics, Champaign, IL, pp. 63–85.

Walter, S. & Hart, L. (1990) Application of epidemiological methodology to sports and exercise science research. In: *Exercise and Sports Reviews* (Pandolf, K. & Holloszy, J., eds.), Williams & Wilkins, Baltimore, pp. 417–448.

Whiteside, P. (1980) Men's and women's injuries in comparable sports. *The Physician and Sports Medicine* **8**(3), 130–140.

Yamamoto, L., Inaba, A., Okamura, D., Yamamoto, J. & Yamamoto, J. (2001) Injury reduction and bounce characteristics of safety baseballs and acceptability by youth leagues. *Clinical Pediatrics* **40**(4), 197–203.

Yen, K. & Metzl, J. (2000) Sports-specific concerns in the young athlete: baseball. *Pediatric Emergency Care* **16**, 575–580.

Zaricznyj, B., Shattuck, L., Mast, T., Robertson, R. & D'Elia, G. (1980) Sports-related injuries in school-aged children. *American Journal of Sports Medicine* **8**(5), 318–324.

Chapter 6

Basketball

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Introduction

Basketball was invented in 1891 by James Naismith, a physical education teacher who recognized the need for an indoor sport during cold winter months. From simple beginnings, basketball has grown in popularity throughout the world. The International Basketball Federation is now comprised of 213 countries and reports that in 2006, 11% of the world played basketball (2008). Basketball was played for the first time at the Olympic Games on August 1, 1936, in Berlin. Women's basketball joined the Olympic program in 1976. Traditionally, basketball has been considered a noncontact sport, but there is now sufficient body contact to suggest that it has evolved into a semicontact sport.

This chapter aims to provide a comprehensive review of the injury literature on adult basketball players from 1990 through 2007. For data on children, youth, and adolescent players, see Harmer (2005).

Who Is Affected by Injury?

Overall Injury Rate

There is a wide range in the overall rate of injury in basketball and considerable variation in how rates are reported (hours of participation, athlete exposures (AEs), athlete per season, participant years, percentage of players), which reflects characteristics of specific surveillance methods and designs. Table 6.1 summarizes injury rates and design parameters (retrospective, prospective) of basketball injury studies.

The definition of a reportable injury can influence the injury rate reported. Definitions comprised of "any injury receiving attention" capture minor injuries that do not result in time lost from participation and produce higher injury rates as compared with definitions based on "time lost from participation." These minor injuries cloud our understanding of the risk associated with playing basketball. For example, McKay et al. (2001b) used a definition of "any injury receiving treatment" and found a rate of 23 to 26.9 per 1,000 hours of participation. However, applying a "time-loss" definition resulted in a rate of approximately 6 per 1,000 hours. Definitions used in the studies listed in Table 6.1 are identified.

In general, most epidemiologic studies in basketball report a relatively low injury rate. The highest rate of injury is reported in professional American basketball (19–25 per 1,000 AEs). Other rates reported in Table 6.1 vary from 1.4 to 9.9 injuries per 1,000 AEs, depending on the definition used and the population sampled.

Where Does Injury Occur?

Anatomical Location

Basketball requires repetitive jumping interspersed with running and rapid change of direction, and this

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Table 6.1 Overall injury rates in basketball.

Study	Design	Duration	Sample	Per 1,000 Hr	Per 1,000 AE	Other Rates
Agel et al. (2007)	R	16 yr	College			
Female					7.7[a]	
Dick et al. (2007)	R	15 yr	College			
Male					9.9[a]	
Deitch et al. (2006)	R	6 seasons	NBA and WNBA			
Male—game-related					19.3[b]	
Female—game-related					24.9[b]	
Meeuwisse et al. (2003)	P	2 yr	College			
Male					4.9[b]	
McKay et al. (2001b)	P	17 mo	Adults			
Male—elite				26.9[b]	26.9[b]	
Male—recreational				22.0[b]	14.7[b]	
Female—elite				23.0[b]	23.0[b]	
Female—recreational				25.7[b]	17.2[b]	
Sallis et al. (2001)	R	15 yr	College			
Male						126.9/100 players/yr
Female						112.0/100 players/yr
Stevenson et al. (2000)	P	5 mo	Adults—recreational	15.1[a]		
Starkey (2000)	R	10 yr	NBA			
Male					21.4[a]	
Arendt & Dick (1995)	R	5 yr	College			
Male				5.6[a]		
Female				5.2[a]		
Crawford & Fricker (1990)	R	8 yr	Elite (16 to 23 yr)			
Female						0.8 participant-years[a]
Lanese et al. (1990)	P	1 yr	College			
Male				4.5[b]		
Female				4.8[b]		

AE = athlete exposure; NBA = National Basketball Association; P = prospective; R = retrospective; WNBA = Women's National Basketball Association.
[a] Any reported injury.
[b] Time loss from reported injury.

pattern is indicated in the lower limb being more affected by injury than the upper limb. Table 6.2 details the distribution of injuries by body region. The lower limb accounts for 46.4% to 68.0% of injuries, while head and neck injuries were responsible for 5.8% to 23.7%. Upper-limb injuries account for 5.6% to 23.2% of injuries, and spine and pelvis injuries for 6.0% to 14.9%.

The most common specific injuries have been detailed in several studies providing more information about specific anatomical sites of injury. Studies reporting injury location-by-type data are summarized in Table 6.3.

The most common lower-limb injuries in basketball occur at the ankle and knee. The prevalence of ankle injuries varies between 10.7% and 76.0% of

Table 6.2 Percent distribution of injuries by anatomical location.

Study	Head/Neck %	Spine/Pelvis %	Upper Limb %	Lower Limb %	Other %
Agel et al. (2007)	14.7	7.4	14.1	60.8	3.0
Dick et al. (2007)	13.9	11.4	14.1	57.9	2.7
Deitch et al. (2006)				65.0	
Meeuwisse et al. (2003)	10.2	6.5	13.5	67.4	2.3
McKay et al. (2001b)	23.7	6.3	23.2	46.8	
Starkey (2000)	8.5	9.5	12.1	46.4	23.5
Crawford & Fricker (1990)	9.6	14.6	5.6	66.0	2.2

all injuries, at rates between 1.5 to 4.3 per 1,000 AEs and 5.2 to 5.5 per 1,000 hours of participation.

The rate of knee injury has been reported between 1.5 and 4.4 per 1,000 AEs and is the most frequent injury reported in professional American basketball players, accounting for 20% of all injuries (Figure 6.1) (Deitch et al. 2006). Anterior cruciate ligament (ACL) damage is a common knee injury, which is often season-ending or, at times, career-ending. Because of its serious nature, several studies have specifically investigated the rates of ACL injuries in basketball (Table 6.3), which vary from 0.03 per 1,000 AEs in a male sample (Agel et al. 2005) to 0.48 per 1,000 AEs in a female sample (Gwinn et al. 2000).

Knee-extensor injuries mostly affect the proximal end of the patellar tendon in basketball players and account for approximately 70% of patellar tendon injury (Blazina et al. 1973).

Although dental injuries are thought to account for only 1% of basketball-related injuries, they are of concern because they can be permanent, disfiguring, and expensive (Labella et al. 2002). Cohenca et al. (2007) conducted a retrospective review of records and reported the incidence of traumatic dental injuries for male and female college basketball players as 10.6 and 5.0 per 100 athlete-seasons, respectively.

Environmental Location

Basketball is played indoors, usually on wooden floors. Early studies suggested that harder floors may be implicated in overuse injuries, specifically patellar tendinopathy (Ferretti et al. 1984); however, the move to better floor surfaces leaves little variation in the basketball environment, and there are no studies investigating how different environments impact injuries (acute or overuse).

Location on the Court

It has been reported that approximately half of all basketball injuries occur in the key, where crowding, jumping, and body contact are common. For example, Meeuwisse et al. (2003) found that injuries in this region accounted for 44.7% of reportable injuries, at a rate of 2.2 injuries per 1,000 AEs.

Competition versus Training

More injuries are sustained during competition than during training sessions. In a 16-year review of men's college basketball in the USA, Dick et al. (2007) found that the rate of injuries in games was two times greater than in practice (9.9 per 1,000 AEs vs. 4.3 per 1,000 AEs; rate ratio, 2.3; 95% CI, 2.2–2.4). In a similar review of women's college basketball, Agel et al. (2007) reported the same findings (7.7 per 1,000 AEs vs. 4.0 per 1,000 AEs; rate ratio, 1.9; 95% CI, 1.9–2.0).

Meeuwisse et al. (2003) reported that 3.7 times more serious injuries occurred in collegiate basketball games (1.9 per 1,000 AEs) as compared with training sessions (0.5 per 1,000 AEs). Agel et al. (2007) reports that female college players were more likely to sustain a concussion (rate ratio, 3.3; 95% CI, 2.8–4.0), knee internal derangement (rate ratio, 3.3; 95% CI, 2.9-3.7) and ankle sprain (rate ratio, 2.0; 95% CI, 1.8–2.2) in a game than in training.

In professional American basketball, (Deitch et al. (2006) reported that female players were injured more frequently at practices as compared with games, while Starkey et al. (2000) reported that 43.2% of injuries in male players over a 10-year period occurred during a game.

Table 6.3 Frequency and rates for common location-by-type injuries.

	Ankle Ligament Sprain		Knee Internal Derangement		Knee		Patella or Patellar Tendon		Upper-Leg Contusion		Lower Back Strain		Nose—Fracture		Head—Concussion	
	%	Per 1,000 AEs	%	Per 1,000 AEs	%	Per 1,000 AEs	%	Per 1,000 AEs	%	Per 1,000 AEs	%	Per 1,000 AEs	%	Per 1,000 AEs	%	Per 1,000 AEs
Agel et al. (2007)[a]																
Female	24.6	1.9	15.9	1.2			2.4	0.2	1.7	0.1	1.3	0.1	1.7	0.1	6.5	0.5
Dick et al. (2007)[a]																
Male	26.2	2.3	7.4	0.7	1.5	0.1	2.4	0.2	3.9	0.3	2.2	0.2	1.7	0.2	3.6	0.3
Deitch et al. (2006)[b]																
Male	17.9	3.5	0.7	0.1	19.1	2.5	4.3	0.8	3.5	0.7	4	0.8	1	0.2	1.2	0.2
Female	17.3	4.3	1.6	0.4	22.5	4.4	4.7	1.2	2.6	0.7	2.8	0.7	1	0.3	2.4	0.6
McGuine & Keene (2006)[a]	8.1	1.5														
Mihata et al. (2006)[b]																
Male			1.4	0.08												
Female			5.2	0.28												
Trojian & Collins (2006)[b]																
Caucasian				0.45												
African-American				0.07												
Agel et al. (2005)[a]																
Male				0.03–0.13												
Female				0.20–0.37									0.03–0.13			
Beynnon et al. (2005)[a]																
Male		0.4/PD														
Female		1.9/PD														
Meeuwisse et al. (2003)[b]																
Male	15.8		1.9						3.3						3.7	
McKay et al. (2001b)[b]	21.1	3.9			13.7	2.5										
Gwinn et al. (2000)[a]																
Male				0.09[a]												
Female				0.48[a]												
Hosea et al. (2000)[a]																
	76.0			For females RR, 3.0; $P < 0.001$												
Starkey (2000)[a]							3.3									
Male	16.1	3.4					0.7		6.9	1.5	4.4	0.9	0.8	0.2		
Sallis et al. (2000)[a]		2.9/PY				1.7/PY										
Arendt & Dick (1995)[a]																
Male			1.2	0.07[a]												
Female			5.7	0.29[a]												
Leanderson et al. (1993)[b]		5.5/Hrs														

AE = athlete exposures; Hr = rate per 1,000 playing hours; PD = rate per 1,000 person-days; PY = rate per 1,000 participant-years; RR = risk ratio.
[a] Any reported injury.
[b] Time loss from any reportable injury.

Figure 6.1 The dynamic running, jumping and cutting of modern basketball are associated with a high percentage of acute and chronic knee injuries. © IOC/Steve MUNDAY

When Does Injury Occur?

Injury Onset

Although few studies differentiate between acute and overuse injuries it appears that overuse injuries account for between 12.8% and 37.7% of all injuries.

Tendinopathies, particularly patellar tendinopathy, are the most common overuse injury. All players are vulnerable, particularly those that are aerial players by nature. Cook et al. (1998) reported a prevalence of patellar tendinopathy diagnosed on imaging in basketball players of 50%. About one third of athletes with patellar tendon changes had imaging abnormalities bilaterally.

Chronometry

Few studies have investigated the time during a game at which injury occurs. McKay et al. (2001a) found no significant relationship between time during a game and ankle injuries.

Three studies have investigated the time during a basketball season during which injury is most common and shown have a higher rate in the preseason as compared with later in the season for both practice and games. In men's collegiate basketball, Dick et al. (2007) reported that the preseason injury rate in practice (7.5 per 1,000 AEs) was almost three times higher than the in-season practice injury rate (2.8 per 1,000 AEs) (rate ratio, 2.7, 95% CI, 2.6–2.8), which was, in turn, 50% greater than the postseason rate of training-related injuries (1.5 per 1,000 AEs) (rate ratio, 1.9; 95% CI, 1.5–2.3). For game-related injuries, the in-season rate (10.1 per 1,000 AEs) was 1.6 times higher than the postseason rate (6.4 per 1,000 AEs) (rate ratio, 1.6; 95% CI, 1.3–1.9). Comparable findings were documented in women's college basketball. Agel et al. (2007) reported that the preseason training-related rate (6.8 per 1,000 AEs) was more than twice as high as during in-season training (2.8 per 1,000 AEs) (rate ratio, 2.4; 95% CI, 2.2–2.4), and the regular season game rate (7.7 per 1,000 AEs) was significantly greater than that for the postseason (5.5 per 1,000 AEs) (rate ratio, 1.4; 95% CI, 1.2–1.7). Stevenson et al. (2000) reported that the injury rate in Australian basketball players was the highest at the start of the season (20 per 1,000 hours) and then significantly declined by the end of the fifth month (10 per 1,000 hours).

Starkey (2000) reported that game-related injuries in professional American basketball increased by 12.4% over a 10-year period. In contrast, Agel et al. (2005) showed that over a 16-year period the game injury rate in female collegiate players had an average annual decrease of 1.8% ($P = 0.04$), and the rate of injury in training sessions had an average annual decrease of 1.3% ($P = 0.05$). No changes were reported over the same period in men's collegiate basketball, either during games (0.8%, $P = 0.28$) or training sessions (0.0%, $P = 0.98$) (Dick et al. 2007).

What Is the Outcome?

Injury Type

Table 6.4 summarizes the percentage distribution of type of injury incurred by basketball players. In general, sprains are the most common type of injury, often accounting for about half the injuries. Other common injuries are contusions and strains.

Time Loss

There is considerable variation in how time loss due to injury and the severity of injury are recorded in basketball studies, making it difficult to give a clear overview. Agel et al. (2007) reported that approximately 25% of game and training injuries caused ⩾10 days to be missed. In a study of elite and recreational Australian basketball players, McKay et al. (2001b) reported that 17.8% of injuries (2.9 per 1,000 AEs) resulted in ⩾1 week away from participation.

Other studies have assessed time loss and severity of injury in terms of the need for surgery or hospitalization. In professional American basketball players, Starkey (2000) reported that 3.7% of players required surgery (1.8 per 1,000 AEs), which accounted for 28.4% of the total days missed.

Knee injuries appear to be responsible for the most time lost, and they required surgery more often than other injuries. In intercollegiate players, Agel et al. (2007) reported that knee internal derangement injuries accounted for 41.9% of game-related and 26.1% of training-related injuries in which >10 days of participation were lost and, on average, knee injuries caused 18.3 days to be missed (Meeuwisse et al. 2003). In professional players, knee injuries were responsible for 13.6% of days lost, and the patellofemoral joint accounted for 13.1% of days lost (Starkey 2000).

Ankle injuries also cause substantial time to be missed. Agel et al. (2007) reported that ankle injuries accounted for 13.2% of game-related and 11.5% of training-related injuries, for which >10 days participation were lost. McGuine and Keene (2006) found that 29% of ankle injuries caused 8 to 21 days to be missed and another 6.4% caused >21 days to be missed. In a sample of Australian players, McKay et al. (2001b) noted most time lost was due to ankle injuries, accounting for 43.3% of injuries for which >1 week was missed, with these injuries occurring at a rate of 1.3 per 1,000 AEs. Meeuwisse et al. (2003) reported that ankle injuries caused, on average, 5.5 days to be missed, while McGuine and Keene (2006) reported a mean of 7.6 days.

In a largely recreational sample, in which 66.3% of the players were over the age of 25 years, McKay et al. (2001b) reported that calf injuries were second to ankle injuries for time lost, accounting for 16.7% of injuries for which ⩾1 week was missed, at a rate of 0.5 per 1,000 AEs.

In professional American players, injuries to the lumbar spine were the third most common injury to cause days to be missed, accounting for 11.0% of all time missed.

Tendinopathy, once it progresses past self-management, can result in extended periods during which the player is unable to train or play. A study of recovery from patellar tendinopathy indicated that more than 33% of players were unable to play for more than 6 months and 18% for 12 months (Cook et al. 1997).

Clinical Outcome

Recurrent injuries are common in basketball. For example, DuRant et al. (1992) reported that 66.7% of athletes who injured their ankles had a history of ankle sprain, and follow-up of ankle injuries after 6 to 18 months have shown that residual ankle symptoms occur in 40% to 50% of cases. Konradsen et al. (2002) found that 7 years after injury, 32% of injured players continued to report residual ankle symptoms.

Recurrent injuries in basketball also involve the knee (DuRant et al. 1992; Meeuwisse et al. 2003), elbow (Meeuwisse et al. 2003), shoulder (DuRant, 1992), hand (Meeuwisse et al. 2003), lumbar spine/pelvic region (Meeuwisse et al. 2003), leg (DuRant et al. 1992), and concussion (Meeuwisse et al. 2003).

Catastrophic injuries are defined by the National Center for Catastrophic Sports Injury Research (NCCSI 2004) in the United States as those that result in a brain or spinal cord injury or skull or spinal fracture and subclassified as fatalities, non-fatal (permanent severe functional disability) and serious (no permanent functional disability

Table 6.4 Percent distribution and rate for injury type.

	Sprain		Strain		Contusion		Overuse		Dental		Other	
	%	Injury Rate per 1,000 AEs	%	Injury Rate per 1,000 AEs	%	Injury Rate per 1,000 AEs	%	Injury Rate per 1,000 AEs	%	Injury Rate per 1,000 AEs	%	Injury Rate per 1,000 AEs
Rechel et al. (2008)												
Male	52.6				18.1							
Female	59.3				6.7							
Deitch et al. (2006)												
Male	37.0	7.2	16.4	3.2	20.4	3.9					1.7	0.3
Female	40.4	10.1	15.2	3.8	19.9	5.0					1.9	0.5
McKay et al. (2001b)	51.6	9.4			25.3	4.6					9.5	1.7
Starkey (2000)	20.9	7.4	16.2	4.1	11.8	4.5			0.9	0.2		
Chan et al. (1993)	55.5		7.1		9.1		16.9				11.4	

but severe injury). The NCCSI provides the most comprehensive data for catastrophic injuries in college basketball. Catastrophic injury rates for male and female basketball players are detailed in Table 6.5. It appears that the risk of catastrophic injury in basketball is small. For college players, 36 catastrophic injuries (9 direct, 27 indirect) were recorded over a 24-year period (1982–1983 to 2005–2006).

Economic Cost

Economic cost is considered in terms of the cost of treatments, loss of earnings, and effect on quality of life. Knowles et al. (2007) found that for American high school athletes ankle and knee injuries were most commonly implicated in monetary costs and direct medical costs were higher for boys basketball ($401: 95% CI = 348–463) than girls basketball ($354; 95% CI = 324–386) (p < 0.01)". de Löes et al. (2000) investigated the cost of knee injuries over a 7-year period in a range of sports in Switzerland by reviewing insurance data. Knee injuries in basketball players had a mean cost of US$1,427 per injury for men and US$1,060 for women. Furthermore, knee injuries were responsible for 30% of the costs for all injuries in male basketball players (US$170 per 1,000 hours of participation) and 34% for female players (US$180 per 1,000 hours).

The other concern with regard to substantial economic cost in basketball is dental injuries.

Table 6.5 Catastrophic injuries in basketball per 100,000 participations.

Group and Mechanism	Rate of Fatalities	Rate of Nonfatal Injuries	Rate of Serious Injuries
Male—college			
Direct	0.29	0.59	1.76
Indirect	6.75	0.00	0.29
Female—college			
Direct	0.00	0.00	0.00
Indirect	1.01	0.00	0.00

Direct injuries resulted directly from participation in the skills of the sport. Indirect injuries were caused by systematic failure as a result of exertion while participating in a sport activity or by a complication secondary to a nonfatal injury. Most commonly, indirect fatalities are cardiac failures.

Treatment costs for dental injuries are invariably high. Labella et al. (2002) studied 50 college teams over one season and noted that 45 dental referrals were required, with a minimum cost estimate for serious dental injuries being US$1,000.

What Are the Risk Factors?

Intrinsic Factors

Intrinsic risk factors implicated in basketball injuries are detailed in the following section. The effect of these factors may be mediated by extrinsic factors, particularly load, and there are few clear cause-and-effect relationships with injury.

Sex

Although a number of studies have found a higher overall rate of injury in female players as compared with male players (in professional American basketball, e.g., Deitch et al. 2006), most have reported no significant differences (Arendt & Dick, 1995; Lanese et al. 1990; McKay et al. 2001a; Sallis et al. 2001).

However, specific sex-related injuries have been noted. For example, Deitch et al. (2006) found that female professional American basketball players sustained significantly more sprains as compared with male players. More importantly, Agel et al. (2005) determined that female players were more than three times as likely to incur an ACL injury as compared with their male counterparts (rate ratio, 3.6; 95% CI, 3.0–4.2), and Gwinn et al. (2000) showed a similar trend (ACL injury rates in women, 0.5 per 1,000 AEs as compared with 0.1 per 1,000 AEs in men; rate ratio, 5.4, $P > 0.05$).

Previously presented sex-related sociocultural differences, including women having less experience in organized sports or being less fit, do not seem to be important. For example, Mihata et al. (2006) showed no change in the rate of ACL injuries per 1,000 AEs in male and female basketball players over a 15-year period (1989–1994: women, 0.29; men, 0.07; 1994–2004: women, 0.28; men, 0.08) despite improvements in these characteristics. Similarly, Agel et al. (2005) showed no change in the rate of ACL injury over a 13-year period in female (0.27 per 1,000 AEs) and male (0.08 per 1,000 AEs) basketball players.

Cook and colleagues (1998, 2000) have found that men may be at greater risk for patellar tendinopathy, documenting considerable prevalence differences between men (42%) and women (18%).

Level of Competition

There is uncertainty regarding whether level of competition is a risk factor for injury in basketball. Dick et al. (2007) reported significantly higher game-related injury rates in Division I men's collegiate basketball (10.8 per 1,000 AEs) than in Division III (9.0 per 1,000 AEs) (rate ratio, 1.2; 95% CI, 1.1–1.3) but not for Division II. Agel et al. (2007) found differences between all three levels in collegiate women: Division I as compared with Division II (8.9 vs. 7.4 per 1,000 AEs; rate ratio, 1.2; 95% CI, 1.1–1.3), and Division III (8.9 vs. 6.6 per 1,000 AEs; rate ratio, 1.3; 95% CI, 1.3–1.5).

In contrast, an Australian study reported no difference in the game-related injury rate between elite (men, 26.9 per 1,000 hours of participation; women, 23.0 per 1,000 hours) and recreational players (men, 22.0 per 1,000 hours; women, 25.7 per 1,000 hours) (McKay et al. 2001a).

Previous Injury

The most commonly documented intrinsic risk factor for ankle injury is a history of ankle sprain (Table 6.6). In the earliest of these studies, Garrick and Requa (1973) reported a significantly higher rate of ankle injury in those with a history of ankle injury (27.7 per 1,000 AEs) as compared with their previously uninjured counterparts (13.9 per 1,000 AE; $P = 0.025$). McGuine and Keene (2006) documented the risk of sustaining an ankle sprain to be twice as high for players who had sustained an ankle injury in the previous 12 months (rate ratio, 2.14; 95% CI, 1.3–3.7) and McKay et al. (2001a) reported that players with a history of ankle sprain were almost five times more likely to injure their ankle as those without a history of ankle injury (rate ratio, 4.9; 95% CI, 2.0–12.5).

Evidence shows that combinations of intrinsic risk factors may have a cumulative effect on the risk of ankle injury. For example, overweight male athletes (body-mass index ⩾95th percentile) with a previous ankle sprain were 9.6 times (McHugh et al. 2006) to 19 times (Tyler et al. 2006) more likely to sustain a noncontact ankle sprain as compared with normal-weight players without a history of ankle sprain.

Table 6.6 Intrinsic risk factors of ankle injury.

Risk Factor	Study	Results
Nonmodifiable		
Being female	Beynnon et al. (2005)	RR, 1.5; 95% CI, 0.8–2.9
	Hosea et al. (2000)	RR, 1.3; $P < 0.001$
Modifiable		
History of ankle injury	Garrick & Requa (1973)	27.7 (history) vs. 13.9 per 1,000 AEs; $P < 0.05$
	McGuine & Keene (2006)	RR, 2.1; 95% CI, 1.3–3.7; $P = 0.005$
	McHugh et al. (2006)	1.2 vs. 0.3 per 1,000 AEs; $P < 0.05$
	McKay et al. (2001a)	RR, 5.0; 95% CI, 2.0–12.5; $P < 0.001$
	Tyler et al. (2006)	2.7 vs. 0.4 per 1,000 AEs; $P < 0.001$
Abnormal body sway/balance	McGuine et al. (2000)	Injury rate, 2.7 (high sway) vs. 0.4 (low sway) per 1,000 AEs; $P < 0.0002$
	Wang et al. (2006)	Anteroposterior sway (RR, 1.2; $P = 0.01$); mediolateral sway (RR, 1.2; $P < 0.001$)
Weight (heavier athletes at increased risk)	McHugh et al. (2006)	Injury rate for BMI ⩾95th percentile, 3.0 per 1,000 AEs; vs. <95th percentile, 0.8 per 1,000 AEs; $P < 0.05$
	Tyler et al. (2006)	2.0 (overweight) vs 0.5 (normal weight) per 1,000 AEs; $P = 0.04$

BMI = body-mass index; RR = rate ratio.

Race/Ethnicity

Trojian & Collins (2006) determined that white female players were 6.6 times more likely to injure their ACL than were black female players (0.45 per 1,000 AEs vs. 0.07 per 1,000 AEs; rate ratio, 6.6, 95% CI, 1.35–31.73).

Balance

Although balance has been examined as a risk factor in youth and adolescent basketball injury (e.g., Plisky et al. 2006, Wang et al. 2006, McGuine et al. 2000), no such studies have involved adult players.

Injury Score

Using a sample of 45 basketball players, Shambaugh et al. (1991) showed that logistic-regression analysis incorporating three structural measures [weight imbalance (lateralization of center of gravity) $\times$ 0.36 + abnormal right quadriceps angle $\times$ 0.48 + abnormal left quadriceps angle $\times$ 0.86 + intercept ($-$7.04)] correctly predicted the injury status of 91% of players. However, Grubbs et al. (1997) applied this injury equation to 62 high-school basketball players and found it to have no predictive value.

Extrinsic Factors

Playing Position

Limited research has investigated whether playing position is a risk factor for injury. Early studies were descriptive in nature but concluded no such relationship (Henry et al. 1982), which has been supported by more recent research on both overall injury rate (McKay et al. 2001a) and risk for ankle injury specifically (Leanderson et al. 1993; McKay et al. 2001b).

In contrast, Meeuwisse et al. (2003) showed that centers had a higher injury rate for knee (rate ratio, 13.0), ankle (rate ratio, 4.5) and foot (rate ratio, 10.0) injuries as compared with forwards, who had the lowest rate.

Shoes

McKay et al. (2001a) reported that basketball players wearing more expensive shoes, which had air cells in the heel, were 4.3 times more likely to injure their ankle than those wearing less expensive shoes (rate ratio, 4.4; 95% CI, 1.5–12.4; $P = 0.01$).

What Are the Inciting Events?

Player contact was responsible for 52.3% of game-related injuries in male collegiate players (Dick et al. 2007) and 46.0% of injuries in female players (Agel et al. 2007) and was the most common mechanism for ankle injuries in both. Meeuwisse et al. (2003) documented a ratio of 4:3 for contact to noncontact injuries also in college players. In an Australian sample, McKay et al. (2001b) reported that 52.1% of injuries were due to body contact but that almost half (45.0%) of the ankle injuries were incurred during landing and another 30% sustained while doing a cutting maneuver.

ACL injuries have been reported as non-contact injuries in 65.2 % of male college players and 80.1% of female college players (Arendt & Dick 1995). Although Krosshaug et al. (2007) found that a majority (71.8%) of ACL injuries were from noncontact mechanisms, they reported perturbation of a movement pattern in the time before injury for many cases. These researchers conducted video analysis of 39 ACL injuries (22 in women, 17 in men) and found that one half (11 of 22) of the ACL injuries in women involved the player being pushed or collided with before the time of injury. A majority (71.8%) occurred while the injured player was in possession of the ball, and over half (56.4%) occurred while attacking. For female players, 59.1% of ACL injuries occurred during single-leg landings, while in male basketball players 35.3% occurred during single-leg landing.

Injury Prevention

As detailed previously, the two most problematic injuries in basketball are related to the ankle and knee (ACL). As a result, greater emphasis on prevention of these injuries is evident in the literature.

Ankle Injuries

Injury-prevention strategies for the ankle have traditionally included the use of external ankle supports (braces or tape), high-cut shoes and functional rehabilitation programs.

External Ankle Support

The use of external ankle support as a protective factor for ankle injuries is well documented in the literature. External ankle support includes the use of both ankle braces and ankle tape. Four systematic reviews, analyzing between 5 and 14 randomized, controlled trials (RCTs) have concluded that ankle braces decrease the incidence of ankle injuries (Handoll et al. 2001; Quinn et al. 2000; Thacker et al. 1999; Verhagen et al. 2000). Handoll et al. (2001) conducted a meta-analysis using 14 RCTs (8,279 participants) and reported a reduction in the number of ankle sprains with the use of external ankle braces (rate ratio, 0.53; 95% CI, 0.40–0.69). This reduction was greatest in those with a history of ankle sprain (rate ratio, 0.33; 95% CI, 0.20–0.53). Handoll et al. (2001) concluded that there is good evidence that ankle braces provide protection for athletes involved in sporting activities considered to present a high risk for ankle injuries, such as basketball. Garrick and Requa (1973) documented the lowest rates of ankle injury in basketball players taping their ankles (ankle tape/high-cut shoes, 6.5 per 1,000 AEs; ankle tape/low-cut shoes, 17.6 per 1,000 AEs) as compared with those not taping their ankles (no tape/high-cut shoes, 30.4 per 1,000 AEs; no tape/low cut shoes, 33.4 per 1,000 AEs). Sitler et al. (1994) studied 1,601 military cadets playing basketball over two seasons and determined that the use of ankle braces significantly decreased the incidence of ankle injuries occurring due to player contact.

Olmsted et al. (2004) calculated the number-needed-to-treat statistic from the basketball injury data of Sitler et al. (1994) and concluded that for one ankle sprain to be prevented in a single basketball season in athletes with a history of sprain, 18 ankles would need to be braced. In athletes without a history of sprain, 39 basketball players would need to wear a brace.

Shoes

In basketball, high-cut shoes were advocated after Garrick and Requa's (1973) study, which reported the lowest rate of ankle injury in players wearing a combination of high-cut shoes and ankle tape (6.5 per 1,000 AEs). However, more recent evidence suggests that the cut of shoe does not affect the incidence of ankle injuries. For example, Barrett et al. (1993) studied 622 basketball players over a 2-month period and reported no difference in ankle injury rates for three types of shoes—low-cut shoes, high-cut shoes, and high-cut shoes with inflatable air chambers—and McKay et al. (2001a) found no association between cut of shoe (low, mid, and high cut) and ankle injuries in a sample of 40 players with ankle injuries and 360 control players.

Functional Rehabilitation

McGuine and Keene (2006) reported that a balance training program (balance board and single-leg functional exercises) significantly decreased the risk of ankle sprains in high-school basketball players as compared with a control group (1.13 per 1,000 AEs vs. 1.87 per 1,000 AEs; $P = 0.04$). Beyond this study, there appears to be a lack of basketball-specific research to demonstrate functional rehabilitation as a protective factor for ankle injuries.

Anterior Cruciate Ligament Injuries

Hewett et al. (1999) used a 6-week preseason neuromuscular training program that was completed three times per week for 60 to 90 minutes per session to assess the impact on the rate of ACL injuries. The rate of noncontact ACL injury decreased by 72% in the intervention group (rate ratio, 0.50; 95% CI, 0.1–2.5).

Dental Injuries

Dental injuries, although infrequent, can be costly; their incidence may be reduced by the use of mouth guards. Labella et al. (2002) conducted a prospective study examining 70,936 AEs from 50 college basketball teams and showed that players wearing custom-made mouth guards had a significantly lower rate of dental injuries (0.12 per 1,000 AEs) as compared with those not wearing mouth guards (0.67 per 1,000 AEs). Despite this, Perunski et al.

(2005) reported low use of mouth guards in Swiss basketball, with only four mouth guards worn in 302 players who reported 55 dental injuries.

Further Research

Injury Surveillance Systems

There is an ongoing need to develop more comprehensive injury surveillance systems in basketball at all levels of participation with a standard definition of a reportable injury and denominator data (exposures) for expressing injury rates. Consistent injury surveillance systems would enable comparisons across studies to be readily made and provide a clearer understanding of injuries in varying basketball populations around the world.

Further research also needs to examine factors such as age, sex, level of experience, and position played on the court, for not only the overall injury profile but also to improve the understanding of specific injuries. The reasons for injuries being more prevalent in the preseason as compared with later in the season also need to be established, and whether a pattern exists as to when injuries occur during games needs to be clarified. There also needs to be more widespread reporting of catastrophic injuries to enable risk factors and preventive strategies to be developed for these life-changing events.

Regarding the major injury categories of ankle and knee injuries, further research of ankle injuries should include investigating the mechanisms of ankle injuries and their role in preventing these injuries, identification of other risk factors for ankle injuries, the role of the sole of the basketball shoe in respect to proprioceptive feedback, and the rate of ankle injury (Robbins and coworkers found that the thickness and hardness of the soles of shoes affected foot position under dynamic conditions, with the thickest and softest soles causing the greatest errors [Robbins et al. 1995; Robbins & Waked 1998]), the impact of functional rehabilitation programs in reducing the risk of ankle injury, clarification of the specific role of ankle taping or bracing in preventing ankle sprains, and the utility of improving physical fitness/conditioning as an effective injury prevention strategy.

Similarly, further research into ACL injuries in basketball should include exploring and confirming risk-factors (including race), determining whether the addition of unexpected changes to normal movement patterns during training improved landing strategies, or whether neuromuscular training programs can decrease the risk of ACL injury in players of varying levels of experience, age groups, and ethnic groups. For example, Krosshaug et al. (2007) found that female players land with more hip and knee flexion and, as a result, were 5.3 times more likely to sustain a valgus collapse than male players (rate ratio, 5.3; $P = 0.002$). In addition, Chandrashekar, Slauterbeck, and Hashemi (2005) argued that the female ACL has a smaller cross-sectional area (mean ±SD: in female players, $58.29 \pm 15.32\,\mathrm{mm}^2$, in male players, 83.54 ± 24.89; $P = 0.007$), is shorter in length (in female players, $26.85 \pm 2.82\,\mathrm{mm}$; in male players, 29.82 ± 2.51; $P = 0.01$), and has a smaller volume (in female players, $1954 \pm 516\,\mathrm{mm}^3$; in male players, 2967 ± 886; $P = 0.003$) as compared to the male ACL. The association of these differences with ACL injury has yet to be substantiated in the epidemiologic literature. Interestingly, Lombardo, Sethi, and Starkey (2005) reported that an 11-year prospective study investigating 305 professional male players showed no significant difference in intercondylar notch width index between players with ACL injuries (0.235 ± 0.031) and those without ACL injuries (0.242 ± 0.041) players ($t_{305} = -0.623$; $P = 0.534$).

Finally, although tendinopathy is currently subject to extensive research at molecular, histologic, and clinical levels, it would be reasonable to say that this research has not yet delivered substantial changes in management. For example, Gaida et al. (2004) found that athletes who had patellar tendinopathy trained for a mean (±SD) of 2.6 ± 1.4 hours more than athletes without tendinopathy but the importance of load, as measured by frequency or volume of participation, has not been adequately explored. Better understanding of tendon pathology, improved exercise options, and understanding those at risk are key to improving management. Most importantly, identifying the source of pain is critical, followed by research that allows the matrix to fully restructure after injury.

References

Agel, J., Arendt, E.A. & Bershadsky, B. (2005) Anterior cruciate ligament injury in National Collegiate Athletic Association basketball and soccer. *American Journal of Sports Medicine* **33,** 524–530.

Agel, J., Olson, D.E., Dick, R., Arendt, E.A., Marshall, S.W. & Sikka, R.S. (2007) Descriptive epidemiology of collegiate women's basketball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988–1989 through 2003–2004. *Journal of Athletic Training* **42**, 202–210.

Arendt, E. & Dick, R. (1995) Knee injury patterns among men and women in collegiate basketball and soccer. NCAA data and review of literature. *American Journal of Sports Medicine* **23,** 694–701.

Barrett, J.R., Tanji, J.L., Drake, C., et al. (1993) High- versus low-top shoes for the prevention of ankle sprains in basketball players. A prospective randomized study. *American Journal of Sports Medicine* **21**, 582–585.

Beynnon, B.D., Vacek, P.M., Murphy, D., Alosa, D. & Paller, D. (2005) First-time inversion ankle ligament trauma. The effects of sex, level of competition, and sport on the incidence of injury. *American Journal of Sports Medicine* **33,** 1485–1491.

Blazina, M.E., Kerlan, R.K., Jobe, F.W., Carter, V.S. & Carlson, G.J. (1973) Jumper's knee. *Orthopedic Clinics of North America* **4,** 665–678.

Chan, K.M., Yuan, Y., Li, C.K., Chien, P. & Tsang, G. (1993) Sports causing most injuries in Hong Kong. *British Journal of Sports Medicine* **27**, 263–267.

Chandrashekar, N., Slauterbeck, J. & Hashemi, J. (2005) Sex-based differences in the anthropometric characteristics of the anterior cruciate ligament and its relation to intercondylar notch geometry. *American Journal of Sports Medicine* **33,** 1492–1498.

Cohenca, N., Roges, R.A. & Roges, R. (2007) The incidence and severity of dental trauma in intercollegiate athletes. *Journal of the American Dental Association* **138,** 1121–1126.

Cook, J., Coleman, B., Khan, K., Kiss, Z. & Griffiths, L. (2000) Patellar tendinopathy in junior basketball players: A controlled clinical and ultrasonographic study of 268 tendons in players aged 14–18 years. *Scandinavian Journal of Medicine and Science in Sports* **10,** 216–220.

Cook, J.L., Khan, K.M., Harcourt, P.R., Grant, M., Young, D.A. & Bonar, S.F. (1997) A cross sectional study of 100 athletes with jumper's knee managed conservatively and surgically. The Victorian Institute of Sport Tendon Study Group. *British Journal of Sports Medicine* **31,** 332–336.

Cook, J.L., Khan, K.M., Harcourt, P.R., Kiss, Z.S., Fehrmann, M.W., Griffiths, L. & Wark, J.D. (1998) Patellar tendon ultrasonography in asymptomatic active athletes reveals hypoechoic regions: a study of 320 tendons. Victorian Institute of Sport Tendon Study Group. *Clinical Journal of Sport Medicine* **8,** 73–77.

Crawford, S.E. & Fricker, P.A. (1990) Injuries and illnesses amongst young elite female basketballers at the Australian Institute of Sport 1982–1989. *Excel* **6**, 6–11.

de Löes, M., Dahlstedt, L.J. & Thomee, R. (2000) A 7-year study on risks and costs of knee injuries in male and female youth participants in 12 sports. *Scandinavian Journal of Medicine and Science* **10**, 90–97.

Deitch, J.R., Starkey, C., Walters, S.L. & Moseley, J.B. (2006) Injury risk in professional basketball players: a comparison of women's national basketball association and national basketball association athletes. *American Journal of Sports Medicine* **34,** 1077–1083.

Dick, R., Hertel, J., Agel, J., Grossman, J. & Marshall, S.W. (2007) Descriptive epidemiology of collegiate men's basketball injuries: National Collegiate Athletic Association injury surveillance system, 1988–89 through 2003–2004. *Journal of Athletic Training* **42,** 194–201.

DuRant, R.H., Pendergrast, R.A., Seymore, C., Gaillard, G. & Donner, J. (1992) Findings from the preparticipation athletic examination and athletic injuries. *American Journal of Diseases of Children* **146,** 85–91.

Ferretti, A., Puddu, G., Mariani, P. & Neri, M. (1984) Jumper's knee: an epidemiological study of volleyball players. *Physician and Sports Medicine* **12,** 97–103.

Gaida, J.E., Cook, J.L., Bass, S.L., Austen, S. & Kiss, Z.S. (2004) Are unilateral and bilateral patellar tendinopathy distinguished by differences in anthropometry, body composition, or muscle strength in elite female basketball players? *British Journal of Sports Medicine* **38,** 581–585.

Garrick, J.G. & Requa, R.K. (1973) Role of external support in the prevention of ankle sprains. *Medicine and Science in Sports* **5,** 200–203.

Grubbs, N., Nelson, R.T. & Bandy, W.D. (1997) Predictive validity of an injury score among high school basketball players. *Medicine and Science in Sports and Exercise* **29,** 1279–1285.

Gwinn, D.E., Wilckens, J.H., McDevitt, E.R., Ross, G. & Kao, T. (2000) The relative incidence of anterior cruciate ligament injury in men and women at the United States Naval Academy. *American Journal of Sports Medicine* **28,** 98–102.

Harmer, P. (2005). Basketball. In: *Epidemiology of Pediatric Sports Injuries: Team Sports* (Maffuli, N. & Caine, D., eds.), Karger, Basel, pp. 31–61.

Handoll, H., Rowe, B., Quinn, K. & De Bie, R. (2001) *Interventions for Preventing Ankle Ligament Injuries.* The Cochrane Library, Oxford.

Henry, J.H., Lareau, B. & Neigut, D. (1982) The injury rate in professional basketball. *American Journal of Sports Medicine* **10**(1), 16–8.

Hewett, T.E., Lindenfeld, T.N., Riccobene, J.V. & Noyes, F.R. (1999) The effect of neuromuscular training on the incidence of knee injury in female athletes: a prospective study. *American Journal of Sports Medicine* **27**, 699–706.

Hosea, T.M., Carey, C.C. & Harrer, M.F. (2000) The gender issue: epidemiology of ankle injuries in athletes who participate in basketball. *Clinical Orthopaedics and Related Research* 45–49.

International Basketball Federation (2008). Official website. URL http://www.fiba.com [accessed on March 10, 2008]

Knowles, S.B., Marshall, S.W., Miller, T., Spicer, R., Bowling, J.M., Loomis, D., Millikan, R.W., Yang, J. & Mueller, F.O. (2007) Costs of injuries from a prospective cohort study of North Carolina high school athletes. *Injury Prevention* **13**, 416–421.

Konradsen, L., Bech, L., Ehrenbjerg, M. & Nickelsen, T. (2002) Seven years follow-up after ankle inversion trauma. *Scandinavian Journal of Medicine and Science in Sports* **12,** 129–135.

Krosshaug, T., Nakamae, A., P,B., Boden, B.P., Engebretsen, L., Smith, G., Slauterbeck, J.R., Hewett, T.E. & Bahr, R. (2007) Mechanisms of anterior

cruciate ligament injury in basketball. Video analysis of 39 cases. *American Journal of Sports Medicine* **35,** 359–367.
Labella, C.R., Smith, B.W. & Sigurdsson, A. (2002) Effect of mouthguards on dental injuries and concussions in college basketball. *Medicine and Science in Sports and Exercise* **34,** 41–44.
Lanese, R.R., Strauss, R.H., Leizman, D.J. & Rotondi, A.M. (1990) Injury and disability in matched men's and women's intercollegiate sports. *American Journal of Public Health* **80,** 1459–1462.
Leanderson, J., Nemeth, G. & Eriksson, E. (1993) Ankle injuries in basketball players. *Knee Surgery, Sports Traumatology, Arthroscopy* **1,** 200–202.
Lombardo, S., Sethi, P.M. & Starkey, C. (2005) Intercondylar notch stenosis is not a risk factor for anterior cruciate ligament tears in professional male basketball players; An 11-year prospective study. *American Journal of Sports Medicine* **33,** 29–34.
McGuine, T.A., Greene, J.J., Best, T. & Leverson, G. (2000) Balance as a predictor of ankle injuries in high school basketball players. *Clinical Journal of Sport Medicine* **10,** 239–244.
McGuine, T.A. & Keene, J.S. (2006) The effect of a balance training program on the risk of ankle sprains in high school athletes. *American Journal of Sports Medicine* **34,** 1103–1111.
McHugh, M.P., Tyler, T.F., Tetro, D.T., Mullaney, M.J. & Nicholas, S.J. (2006) Risk factors for non-contact ankle sprains in high school athletes: the role of hip strength and balance ability. *American Journal of Sports Medicine* **34,** 464–470.
McKay, G., Goldie, P., Payne, W. & Oakes, B. (2001a) Ankle injuries in basketball: injury rates and risk factors. *British Journal of Sports Medicine* **35,** 103–108.
McKay, G.D., Goldie, P.A., Payne, W.R., Oakes, B.W. & Watson, L.F. (2001b) A prospective study of injuries in basketball: a total profile and comparison by gender and standard of competition. *Journal of Science and Medicine in Sport* **4,** 196–211.
Meeuwisse, W.H., Sellmer, R. & Hagel, B.E. (2003) Rates and risks of injury during intercollegiate basketball. *American Journal of Sports Medicine* **31,** 379–385.
Mihata, L.C., Beutler, A.I. & Boden, B.P. (2006) Comparing the incidence of anterior cruciate ligament injury in collegiate lacrosse, soccer and basketball players: Implication for anterior cruciate ligament mechanism and prevention. *American Journal of Sports Medicine* **34,** 899–904.
National Center for Catastrophic Sport Injury Research (NCCSI). (2004) *21st Annual Report* URL http://www.unc.edu/depts/nccsi/ReportData [accessed May 20, 2008]
Olmsted, L.C., Vela, L.I., Denegar, C.R. & Hertel, J. (2004) Prophylactic ankle taping and bracing: a numbers-needed-to-treat and cost-benefit analysis. *Journal of Athletic Training* **39,** 95–100.
Perunski, S., Lang, B., Pohl, Y. & Filippi, A. (2005) Level of information concerning dental injuries and their prevention in Swiss basketball: a survey among players and coaches. *Dental Traumatology* **21,** 195–200.
Plisky, P.J., Rauh, M.J., Kaminski, T.W. & Underwood, F.B. (2006) Star excursion test as a predictor of lower extremity injury in high school basketball players. *Journal of Orthopaedic and Sports Physical Therapy* **36,** 911–919.
Quinn, K., Parker, P., De Bie, R., Rowe, B. & Handoll, H. (2000) Interventions for preventing ankle ligament injuries. *Cochrane Database of Systematic Reviews [computer file]*, CD000018.
Rechel, J.A., Yard, E.E. & Comstock, R.D. (2008) An epidemiologic comparison of high school sports injuries sustained in practice and competition. *Journal of Athletic Training* **43,** 197–204.
Robbins, S. & Waked, E. (1998) Factors associated with ankle injuries: preventive measures. *Sports Medicine* **25,** 63–72.
Robbins, S., Waked, E. & Rappel, R. (1995) Ankle taping improves proprioception before and after exercise in young men. *British Journal of Sports Medicine* **29**(4), 242–247.
Sallis, R.E., Jones, K., Sunshine, S., Smith, G. & Simon, L. (2001) Comparing sports injuries in men and women. *International Journal of Sports Medicine* **22,** 420–423.
Shambaugh, J.P., Klein, A. & Herbert, J.H. (1991) Structural measures as predictors of injury basketball players. *Medicine and Science in Sports and Exercise* **23,** 522–7.
Sitler, M., Ryan, J., Wheeler, B., McBride, J., Arciero, R., Anderson, J. & Horodyski, M. (1994) The efficacy of a semirigid ankle stabilizer to reduce acute ankle injuries in basketball: a randomized clinical study at West Point. *American Journal of Sports Medicine* **22,** 454–461.
Starkey, C. (2000) Injuries and illnesses in the National Basketball Association: a 10-year perspective. *Journal of Athletic Training* 35, 161–167.
Stevenson, M.R., Hamer, P., Finch, C.F., Elliot, B. & Kresnow, M. (2000) Sport, age, and sex specific incidence of sports injuries in Western Australia. *British Journal of Sports Medicine* **34,** 188–194.
Thacker, S.B., Stroup, D.F., Branche, C.M., Gilchrist, J., Goodman, R. A. & Weitman, E. A. (1999) The prevention of ankle sprains in sports: a systematic review of the literature. *American Journal of Sports Medicine* **27,** 753–760.
Trojian, T.H. & Collins, S. (2006) The anterior cruciate ligament tear rate varies by race in professional women's basketball. *American Journal of Sports Medicine* **34,** 895–898.
Tyler, T.F., McHugh, M.P., Mirabella, M.R., Mullaney, M.J. & Nicholas, S.J. (2006) Risk factors for non-contact ankle sprains in high school football players: The role of previous ankle sprain and body mass index. *American Journal of Sports Medicine* **43,** 471–475.
Verhagen, E.A., Van Mechelen, W. & De Vente, W. (2000) The effect of preventive measures on the incidence of ankle sprains. *Clinical Journal of Sport Medicine* **10,** 291–296.
Wang, H.K., Chen, C.H., Shiang, T.Y., Jan, M.H. & Lin, K.H. (2006) Risk-factor analysis of high school basketball player ankle injuries: a prospective controlled cohort study evaluating postural sway, ankle strength, and flexibility. *Archives of Physical Medicine and Rehabilitation* **87**, 821–825.

Chapter 7

Boxing

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Introduction

Boxing (also known as *pugilism*) is the physical skill of fighting with the fists (Stening 1992). Boxing was first included as an Olympic sport for the 23rd Ancient Olympic Games in 688 B.C., and was largely a bare-knuckle activity at that time (Jordan 1993, BBC 2007a). During ancient Roman times, boxing was seen as a spectator event, with slaves often forced to participate. Eventually, boxing in Rome was banned by Caesar Augustus in A.D. 393, after aristocrats who had been participating were being injured (BBC 2007a).

Boxing was not commonly practiced again until the 17th century, and the rules in use today began to develop from standards established in Britain in the early 18th century (BBC 2007b). Organized amateur boxing is thought to have begun around 1880, although boxing was not a part of the modern Olympiad until the 1904 Games (International Olympic Committee 2008). It was omitted from the first two Games of the modern era because it was considered too dangerous, and was again not a part of the 1912 Olympic Games in Stockholm because of a national ban on the sport in Sweden (International Olympic Committee 2008). To be eligible to participate in boxing at the Olympic Games, a boxer must be male and between 17 and 34 years of age on the first day of competition and the boxer's country must be affiliated with the Amateur International Boxing Association (AIBA). Of the 203 recognized National Olympic Committee nations, 195 are affiliated with the AIBA and use their rules to regulate the sport (International Boxing Association 2008).

Competitive bouts in Olympic boxing include four rounds of 2 or 3 minutes each, with a one minute break in between (International Boxing Association 2007). Boxers qualify for the Olympic Games based on regional qualifying tournaments with boxers paired off at random within each of the 11 weight divisions for participation in elimination bouts (International Olympic Committee 2008). Compulsory protective equipment for this sport includes headgear, 10-oz (284 g) gloves, and a custom-fitted mouth guard (Figure 7.1). Scoring within this sport uses a computerized system whereby two of the three judges must award a point to the same boxer within 1 second of each other (International Boxing Association 2007). Points are awarded for blows that, without being blocked or guarded in any way, land with the knuckle part of the closed glove on any part of the front or sides of the head or body above the hips (International Boxing Association 2007).

The purpose of this chapter is to review the distribution and determinants of injuries as reported in the amateur boxing literature. The boxing literature reviewed includes injuries both to boxers

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Figure 7.1 Flyweight (over 45–51 kg) bout at the Athens Olympic Games in 2004. © IOC.

participating under the rules and regulations of the AIBA and military personnel who participate in boxing as part of their training. Military boxing, while still a type of amateur boxing, does not necessarily comply with the rules and regulations of the AIBA. Both groups are discussed in the information provided below.

Methodologic Limitations

Epidemiologic investigations of boxing injuries are limited both in methodologic quality and quantity. Injury surveillance has largely been limited to poorly designed descriptive studies with many different study designs and follow-up periods studied. This hinders the ability to compare studies or to determine injury risks and prevention strategies. Other methodologic limitations common to many of the studies include small sample sizes, inconsistent definitions of injury, selection bias for boxers and mismatching of controls (if used), limited use of the blinding of researchers, the cross-sectional or retrospective nature (or both) of data collection in most studies, variations in the assessment tools used and nonvalidation of assessment tools in a boxing cohort, and limited measurement or discussion of possible confounders for the results seen (including age, sex, socioeconomic status, education, employment, injury sustained outside of boxing, alcohol and drug use, etc.) (Kemp 1995; Jako 2002; Loosemore et al. 2007, Knowles & Whyte 2007; McCrory et al. 2007).

Who Is Affected by Injury?

A comparison of injury rates reported in the literature is shown in Table 7.1. As there are only five studies in the amateur boxing literature that report injury rates, wide variations in the range of results exists. In terms of injuries sustained during competition, rates range from 9.5 to 25.0 per 100 bouts in competition (Estwanik et al. 1984; Porter & O'Brien 1996; Zazryn et al. 2006). Within training, rates have been reported to be between 12.1 and 20.4 injuries per 100 boxers (Porter & O'Brien 1996; Welch et al. 1986; Zazryn et al. 2006). In terms of injury rates based upon exposure time, in competition rate ranges of 920.9 to 1221.4 per 1000 hours has been reported (Porter & O'Brien 1996; Zazryn et al. 2006; Welch et al. 1986). In training, injury rates of 0.5 to 22.1 per 1000 hours have been reported (Zazryn et al. 2006; Welch et al. 1986)

Where Does Injury Occur?

Anatomical Location

Table 7.2 provides a percentage comparison of the anatomical locations of injuries sustained during amateur boxing. The head/face (10.3–100.0%) and

Table 7.1 A comparison of injury rates in competition and training for amateur boxing.

Study	Sample Size	Data Collection	Injury Definition (including participation type when injured)	Competition (C) or Training (T)	Duration of Study	No. of Injuries	Rate per 100 Boxers	Rate per 100 Bouts	Rate per 1,000 hr of Exposure	Rate per 1,000 Athlete Exposures
Amateur										
Estwanik et al. 1984	Not reported	Medical records	Any event requiring medical attention for injuries sustained during competition	C	10 days	85		15.5		77.7
Estwanik et al. 1984	Not reported	Medical records	Notable injuries[a] sustained during competition	C	10 days	52		9.5		47.5
Porter & O'Brien 1996	Not reported	Medical records	Necessitated early stoppage of competition	C	5 mo	64		22.8	920.9	
Zazryn et al. 2006	9	Medical records	Physical damage that required treatment or prevented continuation of competition	C	12 mo	4	44.4	25.0	1221.4	
Porter & O'Brien 1996	147	Questionnaire (monthly)	Necessitated early stoppage of and/or prevented continuation of training	T	5 mo	29	20.4			
Zazryn et al. 2006	33	Medical records	Physical damage that required treatment or prevented continuation of training	T	12 mo	4	12.1		0.5	
Military										
Brennan & O'Connor 1968	Not reported	Medical records	Airmen off duty for ⩾48 hr because of injury sustained during competition	C	7 years	73				6.2
Welch et al. 1986	2100	Medical records	Moderate injury[b] sustained during competition	C	2 years	294	14.0		43.5	
Welch et al. 1986	2100	Medical records	Moderate injury[c] sustained during training	T	2 years	294	14.0		9.4	
Welch et al. 1986	2100	Medical records	Mild injury[c] sustained during either competition or training	C & T	2 years	559	26.6		22.1	

[a] Excludes minor injuries such as nosebleeds, black eyes and lacerations.
[b] Excusing a cadet from physical activity for a minimum of 1 day.
[c] Excusing a cadet from physical activity for ⩾7 days.

Table 7.2 Percent comparison of injury location during competition and training for amateur boxing.

	Amateur							Military					
	Estwanik et al. 1984	Porter & O'Brien 1996	Zazryn et al. 2006	Porter & O'Brien 1996	Zazryn et al. 2006	Jordan et al. 1990	Timm et al. 1993	Brennan & O'Connor 1968	Brennan & O'Connor 1968	Welch et al. 1986	Oelman et al. 1983	Welch et al. 1986	Enzenauer et al. 1989
No. of injuries	52[a]	64	4	29	4	447	1,219	240	73	221	437	73	401
Activity when injured	C	C	C	T	T	C & T	C & T	C	C	C	T	T	T
Study time period	10 days	5 mo	12 mo	5 mo	12 mo	10 yr	15.5 yr	14 yr	7 yr	2 yr	12 yr	2 yr	6 yr
Location of injuries													
Head	48.1	71.9	100.0	10.3	25.0	27.1	33.3	59.2	63.0	54.8	67.7	48.0	67.8
Skull													
Intracranial		51.6	25.0			6.5					42.8		
Face/scalp	26.9	20.3		10.3	25.0	3.4	14.5				19.0		
Orbital region	5.8					5.1	3.6						
Nose	5.8		75.0			7.6	5.8			47.9		35.7	
Mouth/teeth	3.8					2.9	2.5						
Ear	5.8					1.1	1.8						
Neck							5.1			1.4		1.4	
Not further specified/other						0.4				5.5	5.9	10.8	
Spine/trunk	3.8	0.0	0.0	0.0	25.0	16.1	8.6	0.0	0.0	0.0	4.6	1.0	7.2
Upper back/cervical						7.6							
Lower back/lumbar	1.9					4.5	4.0						
Ribs/chest	1.9				25.0	3.8	3.8				0.7	0.5	
Abdomen							0.8					0.5	
Internal						0.2							
Other											3.9		
Upper extremity	44.2	23.4	0.0	48.3	50.0	32.9	36.2	16.3	17.8	39.7	13.5	47.5	16.7
Shoulder	1.9			13.8		7.2	7.7			13.7		25.3	
Upper arm					25.0	0.9	1.3				0.2		
Elbow		3.1			25.0	3.6	3.6			5.5	0.5	4.5	
Forearm						0.7	1.3				0.7		
Wrist	1.9	4.7		34.5[b]		2.9	3.7			11.0		7.7	
Hands/fingers	40.4	15.6		34.5[b]		17.7	18.5			9.6	6.4	10.0	
Not further specified											5.7		
Lower extremity	3.8	4.7	0.0	41.4	0.0	23.9	21.9	0.0	0.0	5.5	4.8	3.6	6.2
Pelvis, hips, groin						1.6	1.3						
Thigh						1.3	3.3			1.4			
Knee	1.9	1.6				8.1	6.4				2.3	1.4	
Lower leg		1.6									0.7		
Ankle	1.9	1.6				6.0	5.6			4.1		2.2	
Foot/Toes						2.7	2.9						
Not further specified				41.4		4.3	2.5				1.8		
Not specified								24.5	19.2				2.0

C = competition; T = training.
[a] Notable injuries (excluded minor injuries such as nosebleeds, black eyes and lacerations).
[b] Hand and wrist injuries reported as one category.

the upper extremities (0.0–50.0%) were the most common regions of injury in all studies (Brennan & O'Connor 1968; Oelman et al. 1983, Rose & Arlow 1983; Estwanik et al. 1984; Welch et al. 1986; Enzenauer et al. 1989; Jordan, Voy etl al. 1990 & Stone 1990; Timm et al. 1993; Porter & O'Brien 1996; Zazryn et al. 2006).

During competitive bouts, head injuries accounted for 48.1% to 100.0% of injuries sustained. In training, however, the proportion of head injuries was lower, at 10.3% to 67.8% (Oelman et al. 1983; Welch et al. 1986; Enzenauer et al. 1989; Porter & O'Brien 1996; Zazryn et al. 2006). Of the injuries to the head, the nose (5.8–75.0%), face (10.3–26.9%), and intracranial region (6.5–51.6%) are the most commonly reported injuries.

For the upper extremity, injuries to the wrist (1.9–34.5%) and hands/fingers (6.4–40.4%) were commonly reported.

Environmental Location

As shown in Table 7.1, there were only five studies in the amateur boxing literature that reported separate injury rates for training and competition (Brennan & O'Connor 1968; Estwanik et al. 1984; Welch et al. 1986; Porter & O'Brien 1996; Zazryn et al. 2006). Injury rates ranged from 9.5 to 25.0 per 100 bouts in competition to 12.1 and 20.4 injuries per 100 boxers in training (Estwanik et al. 1984; Porter & O'Brien 1996; Zazryn et al. 2006).

Three studies have determined injury rates based on exposure time (Welch et al. 1986; Porter & O'Brien 1996; Zazryn et al. 2006). In competition, an injury rate range of 920.0 to 1,221.4 per 1,000 hours has been reported (Porter & O'Brien 1996; Zazryn et al. 2006). In training, rates of 0.5 to 22.1 per 1,000 hours have been reported (Welch et al. 1986; Zazryn et al. 2006).

Two studies reported that over 90% of the exposure time for a boxer is spent in training (Welch et al. 1986; Zazryn et al. 2006). However, both of these studies showed that the majority of injuries (75.2% and 57.1%, respectively) occurred in the competitive setting (Welch et al. 1986; Zazryn et al. 2006). This is in contrast to a self-report, cross-sectional survey of 276 amateur boxers in Australia, which found that 61% of injuries reported by respondents for a 2-year recall were sustained during training activities (Tan et al. 2002).

The specific activities being undertaken at the time of injury have not been the focus of much research. While the sparring phase of training is largely considered to be the time at which most boxers are at an increased risk of injury, only one study has reported sparring injuries separately from other training injuries. That study was based on a 12-month follow-up of boxers with four training injuries reported (75% of these were sustained during sparring).

When Does Injury Occur?

Injury Onset

Only one study collected data on both acute and chronic injuries resulting from boxing participation (Porter & O'Brien 1996). In that study of 147 Irish boxers, 37.9% of injuries sustained in training were reported as being of long-term onset. It was not specified which injuries were of long-term cause.

All other studies in amateur boxing that report chronic injuries have focused on the assessment of chronic neurologic injury. Despite this, one systematic review of the observational studies assessing chronic brain injury in amateur boxers concluded that there was little evidence based on poorly constructed studies that chronic brain injury is associated with participation in amateur boxing (Loosemore et al. 2007).

Chronometry

To date, no research has been conducted in boxing related to the time when injury occurred. What may be relevant is the round (or amount of time into a bout) during which an injury is sustained. Again however, this has not yet been researched.

What Is the Outcome?

Injury Type

A percent comparison of injury types reported for amateur boxing are summarized in Table 7.3. Perusal of this table shows that the most commonly

Table 7.3 Percent comparison of injury types in amateur boxing.

	Amateur			Military				
Study	Estwanik et al. 1984[a]	Timm et al. 1993	Porter & O'Brien 1996	Zazryn et al. 2006	Zazryn et al. 2006	Oelman et al. 1983	Welch et al. 1986	Welch et al. 1986
No. of injuries	52	1219	64	4	4	437	73	221
Activity when injured	C	C & T	C	C	T	T	C	T
Study time period	10 days	15.5 yr	5 mo	12 mo	12 mo	12 yr	2 yr	2 yr
Injury Types								
Concussion		6.1	51.6	25.0		26.3	5.5	8.1
Contusion/hematoma	23.1	24.9	3.1			3.0	32.9	20.8
Dislocation/subluxation		1.3	1.6			1.6	9.6	14.9
Fracture	17.3	4.9	14.1	25.0	25.0	28.1	26.0	21.7
Inflammation/tendinitis	1.9	10.0	4.7				2.7	3.6
Laceration/open wound/bleed	26.9	6.3	6.3	50.0	25.0	0.9		
Sprain/strain	21.1	38.3	15.6		50.0	0.7		28.1
Other intracranial						16.5		
Other	9.6	8.1	3.1			0.5	1.4	2.7
Not specified						22.4		

C = competition; T = training.
[a] Notable injuries (excluded minor injuries such as nosebleeds, black eyes, and lacerations).

reported competitive injury types were lacerations or other bleeding (6.3–50.0%), concussions (5.5–51.6%), contusions or hematomas (3.1–32.9%), and fractures (14.1–26.0%) (Estwanik et al. 1984; Welch et al. 1986; Porter & O'Brien 1996; Zazryn et al. 2006). The most commonly reported training injuries were sprains and strains (0.7–50.0%) and fractures (21.7–28.1%).

Concussions (0.0–71.7%), fractures (particularly of the nose; 10.9–30.0%) and lacerations (generally of the orbital region; 8.7–56.0%) are the most common head injury types sustained during competition bouts (Estwanik et al. 1984; Welch et al. 1986; Porter & O'Brien 1996; Zazryn et al. 2006). Upper-extremity injuries, however, tend to be sprains or strains (0.0–100.0% of all upper-extremity injuries), fractures (0.0–54.2%), contusions (0.0–47.8%), or dislocations (0.0–24.1%).

In terms of acute neurologic injuries resulting from amateur boxing, the most commonly reported type is concussion. Studies have reported the incidence of acute neurologic injury to be between 6.5% and 51.6% of all injuries (Oelman et al. 1983; Jordan et al. 1990; Porter & O'Brien 1996; Zazryn et al. 2006). Porter and O'Brien (1996) reported that cerebral injury occurred in 11.7% of amateur fights. Definitional issues exist for the reporting of concussion in boxing. A concussion could be reported as a direct medical diagnosis by the ringside doctor or could be apparent as a knockout (KO), or as the referee stopping the contest as a result of a head injury (RSC-H). The inclusion and exclusion of any of these variables alters the concussion rate that is reported.

Studies reporting the proportion of bouts that end in KO or RSC-H indicate that these outcomes occur in only 0.6% to 7.8% of bouts (Blonstein & Clarke 1957; Schmidt-Olsen et al. 1990). Further, information about Olympic bouts published since 1980 shows a decreasing trend in the fights that are ended by KO and RSC-H (Figure 7.2).

Time Loss

Time loss from participation in boxing, other activities, or work as result of a boxing injury has not been well studied. Table 7.4 displays the results of time lost because of boxing injury. In military studies,

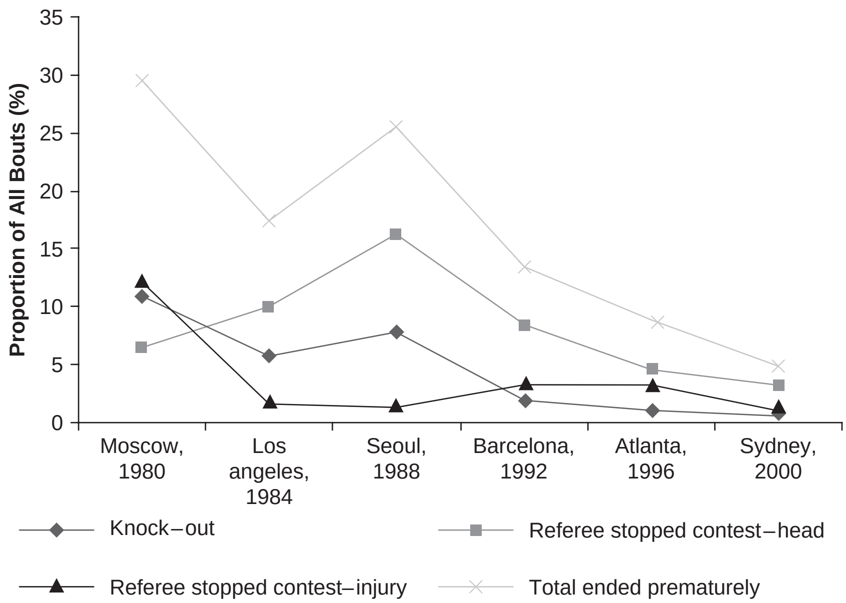

Figure 7.2 Proportion of all Olympic Games bouts ended prematurely since 1980.

a wide variety of measures of time lost hinder the ability to compare results.

Only one study in a nonmilitary population has attempted to measure the effect of boxing injury on participation levels. In their cohort of 142 amateur boxers, Porter and O'Brien (1996) reported that on average a boxing injury sustained during training resulted in 1.2 days of submaximal training.

Injuries sustained during competition in amateur boxing that result in time loss are more difficult to measure because: (a) a mandatory exclusion time exists for AIBA boxers who have been knocked out during a bout; and (b) many boxers do not return to training in the week following a fight, thus measures of time lost could be biased toward a higher figure. According to AIBA rules, boxers who have had one KO or RSC-H, may not compete in a bout or sparring for a period of 4 weeks (International Boxing Association 2007). If a boxer has had two KOs or RSC-Hs in a 3-month period, then a mandatory exclusion period from bouts and sparring of 3 months exists, and if a boxer has three KOs or RSC-Hs within a 12-month period, he may not compete or spar for 1 year (International Boxing Association 2007). In addition, if a boxing association considers that a boxer has received a lot of hard blows during a bout, they may require boxers to discontinue competing or sparring for 4 weeks. At the end of any exclusion periods, a boxer is required to get medical certification before returning to competitive boxing or sparring (International Boxing Association 2007).

Clinical Outcome

Clinical outcomes as a result of amateur boxing injury have only been studied in relation to deaths and brain injury. Fortunately, fatalities appear to be relatively uncommon, with only about one third (190) of the 645 boxing fatalities reported between 1918 and June 1983 occurring in amateur boxers (Ryan 1983). No more recent data on fatalities exist. Fatalities in military boxers have also been reported in the literature, although at low incidence (Enzenauer et al. 1989). Thus, with the exception of discharges from the various military groups (Brennan & O'Connor 1968; Oelman et al. 1983; Ross et al. 1999), and a few case reports of deaths (Cantu & Voy 1995; Ross et al. 1999; Constantoyannis & Partheni 2004), clinical outcomes of injury including the frequency of reinjury, residual symptoms, and nonparticipation are not known.

Table 7.4 Time lost as a result of boxing injuries.

Study	Amateur					Military	
	Porter & O'Brien 1996	Brennan & O'Connor 1968	Welch et al. 1986	Oelman et al. 1983	Welch et al. 1986	Enzenauer et al. 1989	Enzenauer et al. 1989
No. of injuries	29	240	221	437	73	401	401
Activity when injured	T	C	C	T	T	T	T
Study time period	5 mo	14 yr	2 yr	12 yr	2 yr	6 yr	6 yr
Measure of time lost	Average no. of days of submaximal or missed training	Average no. of working days lost (for those off duty for ⩾48 hr)	Median no. of days excused from physical activity	Average no. of days of inpatient stay (for service personnel admitted for ⩾2 days)	Median no. of days excused from physical activity	Average length of stay in hospital (days)	Average no. of sick days
Location of injuries							
Head		9.0[a]		8.8		4.6	8.1
Intracranial			15.0	Concussion, 3.9; subdural hemorrhage, 59.3; cerebral laceration & contusion, 242.0; other, 8.6	15.0		
Face/scalp	0.0			Fractures, 8.9; contusions, 8.0[b]	11.0		
Nose			10.0		11.0		
Neck				Contusions, 8.0[b]	14.0		
Not further specified/other				4.5			
Spine/trunk				18.3		7.5	11.1
Ribs/chest				Fracture, 13.3			
Upper extremity		12.0		12.5		6.2	11.4
Shoulder	14.2		20.0		14.0		
Upper arm				Fracture, 21.0			
Elbow			7.0	Open wound, 88.5[b]	8.0		
Forearm				Fracture, 16.0; open wound, 88.5[b]			
Wrist	4.9[b]		7.0	Fracture, 12.2; open wound, 88.5[b]	18.0		
Hands/fingers	4.9[b]		10.0		Hand, 11.0; finger, 15.0; thumb, 16.0		

(*continued*)

Table 7.4 (*continued*)

Study	Amateur					Military	
	Porter & O'Brien 1996	Brennan & O'Connor 1968	Welch et al. 1986	Oelman et al. 1983	Welch et al. 1986	Enzenauer et al. 1989	Enzenauer et al. 1989
Not further specified				6.1			
Lower extremity				Dislocation,27.6 sprain/strain, 50.7[b]		5.9	10.8
Knee	10.0			Dislocation, 35.4; sprain/strain, 50.7[b]	14.0		
Lower leg	6.4[b]			fracture, 45.3			
Ankle	6.4[b]		19.0		11.0		
Foot/Toes	6.4[b]						
Not further specified				5.5			
Not further specified/other		16.0		6.2		2.8	2.8
All injuries	1.2	11.0		10.4		5.1	8.9

C = competition; T = training.
[a] An additional 3 airmen did not return to work (2 deaths, 1 invalided and discharged).
[b] Reported as the one category.

Nonfatal brain injury is the most severe injury reported in the amateur boxing literature. These include case reports of acute intracranial injuries (including subdural hematomas) (Cruikshank et al. 1980). However, one military article reports that these represent only 0.3% of boxing injuries. This same article reported a rate of serious head injury of 1 per 60,000 boxing participants (Ross et al. 1999). Catastrophic injuries of other types (e.g., permanent disability) have not been reported in the amateur boxing literature. Two case reports of cervical spine fractures that were treated, with both boxers having favorable outcomes (one with no recurrent neurologic deficits, and one with persistent headaches), have also been reported (Place et al. 1996, Ecklund & Enzenauer 1996; Strano & Marais 1983).

Economic Cost

There is no published research on the economic costs of boxing injuries.

What Are the Risk Factors?

Epidemiologic evidence of risk factors for injury in amateur boxing is not well established. Although many authors have hypothesized about factors that may lead to an increased injury risk, only evidence-based assessment of factors related to neurologic injury in amateur boxers has been undertaken. Table 7.5 shows a summary of intrinsic and extrinsic risk factor research related to neurologic injury in amateur boxers.

Intrinsic Factors

Age

The three aspects of a boxer's age that are considered important for injury development include age at commencement of boxing, current age, and the age at which they retire from competition (Jordan 1996; Scott et al. 2001). In active amateur boxers, McLatchie et al. (1987) found that decreasing age was a risk factor for abnormal electroencephalogram (EEG) results. In contrast, Haglund and Persson (1990) reported that EEG deviations were not significantly correlated with age in a group of amateur boxers. Neuropsychological testing also shows conflicting results, with no correlation computed during a cross-sectional study but with increasing age being significantly correlated with reductions in neuropsychological test scores over a 9-year period (Brooks et al. 1987; Porter 2003).

Extrinsic Factors

Exposure

The published literature provides conflicting information on whether or not any exposure variable is a risk factor for injury. McLatchie et al. (1987) have reported significant correlations between an increasing number of fights and a boxer having an abnormal neurologic examination ($P < 0.05$). In univariate analyses, Kemp et al. (1995) showed an inverse relationship between reaction time and pattern recognition between low-bout (≤40 fights) and high-bout (>40 fight) boxers ($P < 0.05$). Significant reductions in finger-tapping speed between boxers with >30 fights and other athletic controls, including lower-bout boxers, have also been shown in the literature (Murelius & Haglund 1991).

No study reports a significant difference between the number of bouts participated in and the results of any neuropsychological tests (Brooks et al. 1987; Butler et al. 1993; Porter & Fricker 1996; Porter 2003; Matser et al. 2000). This includes follow-up studies of boxers of periods from 3 days to 9 years after baseline data-collection measurements (Porter & Fricker 1996; Porter 2003; Moriarity et al. 2004). However, one study reported a significant trend result at baseline (based on increasing odds ratios—all of which had nonsignificant 95% confidence intervals) for the parameters of perceptual/motor function, memory, and visuoconstriction, although this trend was not shown at follow-up 2 years later (Stewart et al. 1994). In addition, a study reporting EEG results, brainstem auditory evoked potentials, and auditory evoked P300 potentials have not shown any significant correlations with the number of bouts (Haglund & Persson 1990).

Haglund and Bergstrand (1990) report a significant correlation between an increasing career length and the occurrence of a cavum septum pellucidum ($P < 0.05$). In this same study, a correlation

Table 7.5 Risk factors for neurologic injury in amateur boxers.[a]

Study	Design	Participants	Assessments	Findings
Thomassen et al. 1979	Case–control, retrospective	53 retired amateurs; 53 former football players	Clinical neurologic and neuropsychological exam, EEG.	No variable was significantly associated ($P>0.05$) with abnormal test results (no. of fights, fights lost, KOs, length of career)
McLatchie et al. 1987	Cross-sectional, retrospective	20 active amateurs	Clinical neurologic and neuropsychological exam, EEG and CT	Abnormal neurologic exam correlated with increasing no. of fights ($P<0.05$). Abnormality on EEG correlated with younger age ($P<0.05$).
Brooks et al. 1987	Case–control, retrospective	29 active amateurs; 11 amateur controls (no sparring); 8 others	Neuropsychological exam.	No significant differences ($P>0.05$) based on number of KOs, wins, losses, RSC-Hs, length of career).
Haglund & Bergstrand 1990; Haglund & Persson 1990; Murelius & Haglund 1991	Case–control, retrospective	50 retired amateurs; 25 soccer players; 25 track and field athletes	Clinical neurologic, physical, and neuropsychological exam, CT, MRI, and EEG.	High match boxers (>30 fights) had significantly lower ($P<0.05$) finger-tapping performance than other groups, but was still within "normal" range. No other exams had significant results ($P>0.05$).
Butler et al. 1993	Interrupted time series with a control group	86 active amateur boxers; 47 rugby union players; 31 water polo players	Neurologic exam, tests of cognitive function, brainstem evoked response, EEG, CKBB and ophthalmologic exam. Done pre-bout, within 6 days of a bout and at 2-yr follow-up. CT post-bout and at 2 yr.	No significant difference between novice and experienced boxers or as a result of no. of bouts on any test ($P>0.05$). More head blows in fights lead to a significantly faster speed of information processing ($P<0.0001$).
Stewart et al. 1994	Interrupted time series without a parallel control group	365 active amateurs	Neuropsychological exam, brainstem auditory evoked potentials, EEG, ataxia/vestibular test battery, interviews, and urine samples. Completed at baseline and then at 2-yr follow-up.	Boxers who had ≥11 fights were more likely to have reduced memory function (OR, 2.23 [95% CI,0.94–5.27]), perceptual/motor skills (OR, 2.21 [95% CI, 0.89–5.43]) and visuoconstructional abilities (OR, 2.20 [95% CI, 0.97–5.02]), as compared with baseline. No changes based on bouts during the follow-up period or as a result of sparring were found ($P>0.05$).

Kemp et al. 1995	Case–control, retrospective	41 boxers; 34 servicemen were controls	Psychometric exam and cerebral perfusion measured by Tc-99m HMPAO SPECT.	Low-bout boxers (<40 bouts) performed better than high-bout boxers for reaction time and pattern recognition ($P<0.05$).
Porter & Fricker 1996	Interrupted time series with a control group	20 active amateurs; 20 controls matched for age and socioeconomic status	Neuropsychological exam. Done at baseline and 15–18 mo later.	There was no significant association ($P>0.05$) between tests scores at baseline or follow-up for length of career, no. of bouts, percentage of losses, weight division or education level.
Matser et al. 2000	Controlled before–after	38 active amateurs having a fight; 28 active amateurs not having a fight but asked to exercise were controls	Neuropsychological exam before and after a bout.	Greater weight and number of punches in the fight significantly reduced short-term memory ($P = 0.02$). Lower ranked boxers (won fewer than 3 fights) showed slower response in the direct attention test ($P = 0.01$). Boxers who had a KO performed better at the puncture test with their nondominant hand ($P = 0.04$). No statistical differences existed based on winning, losing, or drawing ($P>0.05$).
Porter 2003	Interrupted time series with a control group	39 active amateurs; 28 age-matched males training at a gym or living in same suburb were controls	Neuropsychological exam. Done at baseline; 18 mo; 4 yr; 7 yr & 9 yr.	No significant correlations ($P>0.05$) between performances in any test with sparring frequency, no. of bouts or KOs/RSC-H or percentage of wins. Increasing age and lower education levels significantly reduced test scores (coefficients of greater than 0.5).
Moriarity et al. 2004	Interrupted time series with a control group	82 active amateurs; 30 age-matched university students were controls	Physical and computerized neuropsychological exam. Done 2 wk prior to a tournament and within 2 hr of a bout competed in at that tournament.	An improvement in learning performance was seen between boxers who had 3 bouts and their baseline results ($P<0.05$). Compared to baseline, boxers with RSC-H had significant declines in reaction times ($P>0.01$) and boxers with epistaxis had a slowing of choice reaction time ($P<0.01$).

EEG = electroencephalogram; CI = confidence interval; CKBB = creatine kinase isoenzyme BB; CT = computed tomography; MRI = magnetic resonance imaging; OR = odds ratio;Tc-99m HMPAO SPECT = technetium-99m hexamethylpropyleneamineoxime single-photon emission computed tomography.

[a] While studies that included control groups are reported here, only the results for the boxing groups are shown; results comparing boxers with control groups have been omitted.

with the number of fights lost by a boxer and the number of KOs or RSC-H were also significantly associated with cavum septum pellucidum findings ($P < 0.05$) (Haglund & Bergstrand 1990). Other studies, however, have reported that an increasing number of KO, TKO, or RSC-H results have been correlated with improvements between baseline and post-bout measurements for simple and choice reaction times ($P < 0.01$) and nondominant hand puncture ($P = 0.04$) tests (Matser et al. 2000; Moriarity et al. 2004). Two studies have found no differences between injury outcome and the number of KO/TKO or RSC-H results (Murelius & Haglund 1991; Porter 2003). No significant results either at baseline or at up to a 9-year follow-up have been shown in relation to sparring exposure or win/loss percentages and neuropsychological test results (Brooks et al. 1987; Stewart et al. 1994; Matser et al. 2000; Porter 2003).

What Are the Inciting Events?

Only one study has reported inciting events leading to boxing injuries (Tan et al., 2002). In this study, factors thought to contribute to head injuries included a loss of concentration (40.0%), poor technique (27.3%), mismatching of opponents (14.6%), not using headgear (3.6%), and illegal blows by an opponent (foul; 3.6%).

Injury Prevention

A number of measures have been put in place in amateur boxing over the past few decades to decrease the likelihood of poor outcomes associated with participation in the sport (Jako 2002). These include:

- careful medical control
- use of protective equipment
- improved refereeing; and
- mandatory exclusion

No randomized, controlled trials have been conducted to evaluate the efficacy of any injury-prevention techniques for amateur boxing. The only study in which the potential effectiveness of injury-prevention strategies in boxing was a retrospective analysis of the number of bouts ended by KO or RSC-H in Denmark (Schmidt-Olsen et al. 1990). Throughout each of the 3 years studied, different rules (in terms of headgear use, glove weight, and hand bandages) were in place for amateur competition. No significant change in the number of bouts ended early was seen in the later years in which headgear was worn, glove weight was increased, and hand bandaging was allowed (Schmidt-Olsen et al. 1990).

Further Research

Informed decisions regarding injury-prevention practices in amateur boxing require accurate and reliable data on the distribution and determinants of injury. The amateur boxing literature is replete with case series and case–control studies, mainly related to neurologic injury, but is lacking in basic epidemiologic description and cohort studies for prospective longitudinal follow-up of boxers. As such, the details regarding injury risks that could be used to inform injury prevention are not yet known. Therefore, the establishment of larger-scale surveillance systems to document current and reliable data on injury trends and risk factors for amateur boxing are needed.

An international surveillance system that includes all AIBA countries and uses a standardized injury definition would help correct many of the methodologic limitations of past research. In particular, this surveillance system should aim to include the following information:

- demographic details of boxers (including date of birth, country of origin, year of boxing registration, etc);
- medical reports (details obtained from preregistration, annual, and prefight and postfight medical checks);
- fight details (including date, weight at weigh-in, opponent name, opponent's weight at weigh-in, venue, number of scheduled and completed rounds, fights results, etc);
- injury details from competition (including date of injury, specific body region injured, injury nature, specific mechanism of injury, any contributing factors, use of protective equipment, medical diagnosis, treatment given, measure of impact—time off sport/work, and date of return to training/sparring/competition);
- weight difference between competitors at the time of a competitive bout;

- details of any exclusion periods imposed and compliance with these;
- training exposure (including amount of training and sparring, activities undertaken, etc); and
- training injuries (including date of injury, specific body region injury, injury nature, specific mechanism of injury, any contributing factors, use of protective equipment, medical diagnosis, treatment given, measure of impact—time off sport/work, and date of return to training/sparring/competition).

Risk factors yet to be studied within the amateur boxing literature include sex, weight (either at the time of the fight, differences between competitors, or loss in the lead up to a fight), the physical condition of the boxer (including conditioning, strength, biomechanics), boxing skill/technique/performance, preexisting medical conditions, previous injury, genetics, psychological factors, the equipment used (including the ring, gloves, hand bandages, groin protectors, and headgear), variations in rules and regulations, the medical support given, and the training practices and injury treatment and prevention knowledge of trainers and boxers.

This review of the amateur boxing injury literature highlights the need for larger-scale, prospective surveillance systems to be developed and implemented. Such surveillance is needed to determine the risk factors for injury development for this sport as the current available literature fails to provide evidence for injury prevention strategies to be developed.

References

BBC. (2007a) *Early Boxing History.* BBC Co. URL http://www.bbc.co.uk/london/sport/boxing/early_history.shtml [accessed on April 14, 2007]

BBC. (2007b) *A London Revival—Part 1.* BBC Co. URL http://www.bbc.co.uk/london/sport/boxing/london_revival.shtml [accessed on April 14, 2007]

Blonstein, J. & Clarke, E. (1957) Further observations on the medical aspects of amateur boxing. *British Medical Journal* **1**, 362–364.

Brennan, T. & O'Connor, P. (1968) Incidence of boxing injuries in the Royal Air Force in the United Kingdom 1953–1966. *British Journal of Industrial Medicine* **25**, 326–329.

Brooks, N., Kupshik, G., Wilson, L., Galbraith, S. & Ward, R. (1987) A neuropsychological study of active amateur boxers. *Journal of Neurology, Neurosurgery, and Psychiatry* **50**, 997–1000.

Butler, R., Forsythe, W., Beverly, D. & Adams, L. (1993) A prospective controlled investigation of the cognitive effects of amateur boxing. *Journal of Neurology, Neurosurgery, and Psychiatry* **56**, 1055–1061.

Cantu, R. & Voy, R. (1995) Second impact syndrome: A risk in any contact sport. *The Physician and Sportsmedicine* **23**, 27–34.

Constantoyannid, C. & Partheni, M. (2004) Fatal head injury from boxing: A case report from Greece. *British Journal of Sports Medicine* **38**, 78–79.

Cruikshank, J., Higgens, C. & Gray, J. (1980) Two cases of acute intracranial haemorrhage in young amateur boxers. *The Lancet* **1**, 626–627.

Enzenauer, R., Montrey, J., Enzenauer, R. & Manning Mauldin, W. (1989) Boxing-related injuries in the US Army, 1980 through 1985. *Journal of the American Medical Association* **261**, 1463–1466.

Estwanik, J., Boitano, M. & Ari, N. (1984) Amateur boxing injuries at the 1981 and 1982 USA/ABF national championships. *The Physician and Sportsmedicine* **12**, 123–128.

Haglund, Y. & Bergstrand, G. (1990) Does Swedish amateur boxing lead to chronic brain damage? 2. A retrospective study with CT and MRI. *Acta Neurologica Scandinavica* **82**, 297–302.

Haglund, Y. & Persson, H. (1990) Does Swedish amateur boxing lead to chronic brain damage? 3. A retrospective clinical neurophysiological study. *Acta Neurologica Scandinavica* **82**, 353–360.

International Boxing Association (2007) *Rules for International Competitions or Tournaments.* Maison du Sport International. URL http://www.aiba.org [accessed on January 10, 2008]

International Boxing Association. (2008) *Affiliated National Federations: Directory.* Maison du Sport International. URL http://www.aiba.org [accessed on January 10, 2008]

International Olympic Committee (2008) *Boxing.* Official website of the Olympic Movement. URL www.olympic.org/uk/index_uk.asp [accessed on May 12, 2008]

Jako, P. (2002) Safety measures in amateur boxing. *British Journal of Sports Medicine* **36**, 394–395.

Jordan, B. (1993) General concepts. In: *Medical Aspects of Boxing* (Jordan, B., ed.), CRC Press, Boca Raton, FL, pp. 4–10.

Jordan, B. (1996) Boxing. In: *Epidemiology of Sports Injuries* (Caine, D., Caine, C. & Lindner, K., eds.), Human Kinetics Publishers, Inc., Champaign, IL, pp. 113–123.

Jordan, B., Voy, R. & Stone, J. (1990) Amateur boxing injuries at the US Olympic Training Center. *The Physician and Sportsmedicine* **18**, 81–90.

Kemp, P. (1995) A critique of published studies into the effects of amateur boxing: Why is there a lack of consensus? *Journal of the Royal Naval Medical Service* **81**, 182–189.

Loosemore, M., Knowles, C. & Whyte, G. (2007) Amateur boxing and risk of chronic traumatic brain injury: systematic review of observational studies. *British Medical Journal.* **335,** 809.

Matser, E., Kessels, A., Lezak, M., Troost, J. & Jordan, B. (2000) Acute traumatic brain injury in amateur boxing. *The Physician and Sportsmedicine* **28**, 87–92, 95–96.

McCrory, P., Zazryn, T. & Cameron, C. (2007) The evidence for chronic traumatic encephalopathy in boxing. *Sports Medicine* **37**, 467–476.

McLatchie, G., Brooks, N., Galbraith, S., Hutchison, J., Wilson, L., Melville, I. & Teasdale, E. (1987) Clinical neurological examination, neuropsychology, electroencephalography and computed tomographic head scanning in active amateur boxers. *Journal of Neurology, Neurosurgery, and Psychiatry* **50**, 96–99.

Moriarity, J., Collie, A., Olson, D., Buchanan, J., Leary, P., McStephen, M. & McCrory, P. (2004) A prospective controlled study of cognitive function during an amateur boxing tournament. *Neurology* **62**, 1497–1502.

Murelius, O. & Haglund, Y. (1991) Does Swedish amateur boxing lead to chronic brain damage: 4. A retrospective neuropsychological study. *Acta Neurologica Scandinavica* **83**, 9–13.

Oelman, B., Rose, C. & Arlow, K. (1983) Boxing injuries in the Army. *Journal of the Royal Army Medical Corps* **129**, 32–37.

Place, H., Ecklund, J. & Enzenauer, R. (1996) Cervical spine injury in a boxer: Should mandatory screening be instituted? *Journal of Spinal Disorders* **9**, 64–67.

Porter, M. (2003) A 9-year controlled prospective neuropsychologic assessment of amateur boxing. *Clinical Journal of Sport Medicine* **13**, 339–352.

Porter, M. & Fricker, P. (1996) Controlled prospective neuropsychological assessment of active experienced amateur boxers. *Clinical Journal of Sport Medicine* **6**, 90–96.

Porter, M. & O'Brien, M. (1996) Incidence and severity of injuries resulting from amateur boxing in Ireland. *Clinical Journal of Sport Medicine* **6**, 97–101.

Ross, R., Ochsner, M. & Boyd, C. (1999) Acute intracranial boxing-related injuries in U.S. Marine Corps recruits: report of two cases. *Military Medicine* **164**, 68–70.

Ryan, A. (1983) Eliminate boxing gloves. *The Physician and Sportsmedicine* **11**, 49.

Schmidt-Olsen, S., Kallund Jensen, S. & Mortensen, V. (1990) Amateur boxing in Denmark: the effect of some preventive measures. *The American Journal of Sports Medicine* **18**, 98–100.

Scott, I., Finch, C., Ozanne-Smith, J., Eime, R., Staines, C. & Clapperton, A. (2001) *Counting Injuries Out of Boxing*. Monash University, Melbourne, Australia.

Stening, W. (1992) Boxing. *The Medical Journal of Australia* **156**, 76–77.

Stewart, W., Gordon, B., Selnes, O., Bandeen-Roche, K., Zeger, S., Tusa, R., Celentano, D., Shechter, A., Liberman, J., Hall, C., Simon, D., Lesser, R. & Randall, R. (1994) Prospective study of central nervous system function in amateur boxers in the United States. *American Journal of Epidemiology* **139**, 573–588.

Strano, S. & Marais, A. (1983) Cervical spine fracture in a boxer—a rare but important sporting injury: a case report. *South African Medical Journal* **63**, 328–330.

Tan, S., Ghougassian, D., Baker, W. & Johnson, P. (2002) Profile of head injuries in NSW amateur boxing. Advanced Sports Research Institute, New South Wales Australia.

Timm, K., Wallach, J., Stone, J. & Ryan III, E. (1993) Fifteen years of amateur boxing injuries/illnesses at the United States Olympic Training Center. *Journal of Athletic Training* **28**, 330–334.

Thomassen, A., Juul-Jensen, P., De Fine Olivarius, B., Braemer, J. & Christensen, A. (1979) Neurological, electroencephalographic and neuropsychological examination of 52 former amateur boxers. *Acta Neurologica Scandinavica* **60**, 352–362.

Welch, M., Sitler, M. & Kroeten, H. (1986) Boxing injuries from an instructional program. *The Physician and Sportsmedicine* **14**, 81–89.

Zazryn, T., Cameron, P. & McCrory, P. (2006) A prospective cohort study of injury in amateur and professional boxing. *British Journal of Sports Medicine* **40**, 670–674.

Chapter 8

Cycling

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Introduction

Cycling was included in the first modern Olympic Games in 1896. For almost a century, road racing at the Olympics was a male-dominated sport. It was not until 1984 that women competed in the first-ever Women's Olympic road race. During the 2008 Beijing Olympic Games both men's and women's road races comprised the events that made up the Olympic road-racing category.

In the early years, competitive cycling was limited to open-road, mass-start style racing. Figure 8.1 is an image from the 2004 Olympic road race in Athens. This discipline of cycling still exists, but many other forms have become recognized as an Olympic sport. Of them, track racing was the next to be introduced as an Olympic sport in 1924. During track events, riders race around in circles on a 42-degree-banked track. Olympic-level track racing is comprised of many subcategories, including Individual Pursuit, Points, Sprint races, Kierin, Madison, and Team Pursuit races. Of these, women do not compete in the first four of these events.

At the 1996 Atlanta games the Time Trial was introduced. Riders were chosen from their respective

Figure 8.1 This is an image taken during the Cycling Individual Road Race at the 2004 Olympic games in Athens. © IOC/Shiniciro TANAKA.

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countries to compete individually, against the clock, in time-trial fashion. Time trials are open-road style racing, but have an individual-start format. Racers typically start at 90-second intervals and race on a course designed to be completed in under an hour.

Also in Atlanta, MTB racing was first represented in the Olympic Games. Olympic MTB racing consists of cross-country (CC) and downhill (DH) racing. During a CC event racers compete on very hilly, sometimes mountainous courses. The race is a test of their riding skill and pedaling endurance against other racers. These races begin as mass-start events but because of the variable terrain, the pack of riders usually break into small groups quickly after the start. During a DH event, racers race against the clock in time-trial format, mostly down the mountain. The typical race duration is quite short, lasting anywhere between 2 and 10 minutes.

BMX races were included for the first time in the 2008 Olympic games in Beijing, China. BMX races are held on dirt tracks with abundant banked turns and jumps. The track is usually around 350 m long. The riders compete in "heats" (qualifying rounds, quarter-finals, semifinals, and finals), with the top four qualifying for the next round.

The purpose of this chapter is to review the epidemiology of the injuries that occur in the Olympic events of cycling. The specific cycling disciplines include Road Racing, Track Racing, Mountain Biking (MTB), and BMX. These disciplines were introduced to the Olympic Games at different times throughout the last century.

There are very few published studies in the medical or cycling literature concerning the epidemiology of injury in cycling. The sport itself is wrought with tradition, superstition, and folklore, none of which relates well to the scientific investigation of sports injuries. To our knowledge, this is the first attempt to create a review of the published literature on the epidemiology of cycling injuries as they relate to Olympic-level competition.

Notably, none of the studies reviewed in this chapter are prospective cohort studies. The limited research that does exist is mainly in the form of case studies, cross-sectional surveys, and case–control designs. Each of these methods of data collection has inherent inaccuracies, mainly in the form of subjective self-reporting and low response rates. Thus, there is concern regarding the representative quality of the studies reviewed.

Who Is Affected by Injury?

Cycling, apart from competition, is thought by many to be a relatively safe form of aerobic exercise. By way of eliminating repeated foot-to-ground contact, the sport is a great means of developing cardiovascular fitness without the impact of large forces in the musculoskeletal system. However, the sport of competitive cycling requires much higher speeds and much higher muscle and joint loads than recreational cycling. This predisposes the competitive cyclist to increased risk of injury during the considerable time spent training and racing. The typical Olympic-level cyclist races 50 to 80 days a season and trains 20 to 40 hours/wk in preparation (Olympic Movement 2008).

While many studies have shown injury rates and characteristics of recreational cycling (Chow et al 1993), as meant very few have studied the competitive population. Because of the high speeds associated with competitions the sport experiences significant and frequent crashes and subsequent injuries. Table 8.1 shows a comparison of injury rates across cycling disciplines gathered from mainly retrospective, survey-based studies. The MTB discipline of competitive cycling has been the most heavily studied in terms of injury rates. This interest is not surprising, considering that this sport experiences a relatively high rate of injury because of thevariable terrain on which the mountain biker races.

The first-ever study analyzing injury rates in competitive mountain biking was published by Kronisch and Rubin (1994). Of the 265 racers surveyed, 86% reported at least one injury in the previous year. These results suggest that Olympic-level MTB racing is quite dangerous. But, on further analysis, it was obvious that some of the injuries reported were very minor. Of the reported injuries, only 20.4% required medical attention.

Table 8.1 Published studies on injuries in competitive cycling.

Study	Type of Cycling	Design/Data Collection	No. of Participants (surveys received/ surveys sent)	Duration of Data Collection	Results
Kronisch & Rubin (1994)	MTB	R/Q	265 surveys sent	1 yr	85.7% of the 265 studied were injured in the year 1992; 20.4% required medical attention.
Pfeiffer (1993)	MTB	R/Q	63	1 yr	90.5% of the 63 surveyed were injured in the year 1991.
Pfeiffer (1994)	MTB	R/Q	61	1 yr	88.5% of the 61 surveyed were injured in the year 1992.
Krosnich et al. (1996)	MTB	Observational	4027	3 days of off-road racing, one single event	Overall injury rate of 0.49% for CC and 0.51% for DH; 0.37 injuries/100 hr racing for CC, 4.34/100 hr for DH.
Pfeiffer & Kronisch (1995)	MTB	Observational/I	8,804	3 different events on NORBA calendar	Overall injury rate of 0.45%, with no differences between DH and CC.
Callaghan & Jarvis (1996)	Rd, Tr, MTB	R/Q	92/71	1990–1995	Low back pain was reported in 60% of racers, 33% reported knee pain.

BMX = BMX; CC = cross country; DH = downhill; MTB = mountain; I = interview; NORBA = National Off-Road Bicycle Association; P = prospective; Q = questionnaire; R = retrospective; Rd = road; Tr = track.

Using riders from the National Off-Road Bicycle Association (NORBA) racing series, Pfeiffer (1993, 1994) collected data on the rates of injury in the pro/elite category. During 1993, 57 of the 63 riders surveyed reported an injury and in 1994, 54 of the 61 racers reported at least one injury.

It was clear that a new criterion for "injury" was needed. In 1996, Kronisch went to Mammoth Lakes, CA, for the NORBA series final and reported on the frequency of injuries across the five events: cross-country, downhill, dual slalom, hill climb and eliminator (Kronisch, R.L., Pfeiffer, R.P. & Chow, T.K. (1996). A criterion for injury documentation was that medical attention was required. In total, 4,027 racers competed in Mammoth Mountain for the 1996 study. Of these, 16 were injured. The overall injury rate, for all events, was 0.40%. However, of the 16 injuries, 13 occurred during downhill sections of the course in either the cross-country, downhill, or eliminator event.

Pfeiffer and Kronisch (1995) prospectively studied injuries occurring during three off-road cycling events. The overall injury rate was 0.45% (or 40 of the 8,804 racers observed). No difference was found between the cross-country and downhill events. No effects of sex were found for cross-country and downhill, but interestingly, women appeared more likely than men to sustain an injury during the eliminator event (2.17% vs. 1.61%).

Where Does Injury Occur?

Anatomical Location

Callaghan and Jarvis (1996) studied the relative frequency of injuries sustained to various areas of the body in a group of 71 competitive racers injured during 1990–1995. They reported that low back pain was the leading site of injury among their studied population of cyclists. Of the 71 questionnaires returned for analysis, 60% reported low back pain, 33% knee pain, and 30% neck or shoulder pain or both. Quite surprisingly, only 5.6% reported any groin pain, which commonly affects recreational cyclists (Dettori & Norvell 2006).

The data generated by Callaghan and Jarvis (1996) would seem contradictory to research collected in the United States, which suggests that the knee is the most injured area of the body during competitive cycling (Holmes et al. 1991). However, Holmes et al. (1991) found that the knee was the most commonly injured body part in the lower extremity, not in the entire body.

Environmental Location

The only published data regarding environmental location arise from the sport of mountain biking. Kronisch et al. (1996) reported that 81% of accidents occur during downhill sections of the course when speed is speculated to be at its peak.

When Does Injury Occur?

Injury Onset

There are no published data on the relative pro-portions of injury related to injury onset. However, it is reported that overuse injuries of the low back and the pelvis are very common in elite cyclists (Callaghan & Jarvis, 1996). They can range from a simple muscle strain of the gluteals to bursitis, peritoneal/genital compression injury. and arteriosclerosis in the groin region (Holmes et al. 1991, 1995).

Chronometry

Specific data on the incidence rates and timing of injuries sustained by racers are currently not available.

What Is the Outcome?

Injury Type

In the recreational population of riders, the knee accounts for more overuse injuries (Bassett et al. 1978; Hannaford et al. 1989; Holmes et al. 1991; Burke 1990). But, among the competitive population of cyclists, back pain (Callaghan & Jarvis 1996) appears to be the most prevalent condition. In the British study between the years of 1993–1995, the prevalence of back injury, classified as requiring medical care, was 60% (Callaghan & Jarvis, 1996). The comparable figure for knee pain was 33%. However, the results indicate that Callaghan and Jarvis (1996) considered only patellofemoral knee pain. This restriction would severely underestimate the true injury rate of the total knee joint.

Knee injuries are classified as anterior, posterior, medial, and lateral in location. Holmes et al. (1991) studied 354 cyclists and categorized their knee injuries by the location of the injury and the level of the cyclist. As shown in Table 8.2, the anterior knee is the most commonly injured area across all levels of cyclists in their study. The diagnoses include chondromalacia, patellar tendinitis, quadriceps tendinitis, and patellofemoral disease.

Friction and pressure at the interface between the saddle and the perineum cause considerable problems for the cyclist. The most benign of the problems are termed "saddle sores" by the vast majority of cyclists. These sores can be very problematic for the elite cyclist and may even progress into a cyst, which can end a cyclist's season prematurely.

Perineal/genital conditions may also affect the cyclist and include painful urination, prostatitis, urinary tract infections, and sexual dysfunction (Dettori & Norvell, 2006). Iliac artery endofibrosis is also a concern among competitive cyclists (Chevalier et al. 1985). Urinary strictures have also been identified in BMX athletes (Delaney & Carr 2005). However, no data exist on the frequency of these conditions among competitive cyclists.

Table 8.2 Incidence of overuse knee injuries in 354 cyclists (may have more than one diagnosis).

	Level I (elite)	Level II (competitive)	Level III (recreational)
Number of cyclists	58	122	174
		Anterior	
Chondromalacia	15	56	87
Patellar tendinitis	17	15	21
Quadriceps tendinitis	8	4	6
Patellofemoral disease	—	1	12
% of Cyclists	68.9	62.3	72.4
		Medial	
Medial capsule/plica	7	18	6
Medial retinaculum/patellofemoral ligament	5	7	12
Plica and medial patellofemoral ligament	8	3	2
Pes anserinus	—	3	5
% of Cyclists	34.5	25.4	14.4
		Lateral	
Iliotibial band syndrome	13	26	46
% of Cyclists	22.4	21.3	26.4
		Posterior	
Hamstring	10	3	2
Posterior capsule	—	4	3
% of Cyclists	17.2	5.7	2.9

From: Holmes, J.C., Pruitt, A.L., & Whalen, N.J. (1991) Cycling overuse injuries. *Cycling Science* **3**(2), 11.

Ulnar- and medial-nerve palsy at the wrist has been called “cyclist’s palsy” and has long been identified as a cycling-specific injury affecting competitive cyclists because the nerves are compressed for long periods of time. The results of one prospective study indicate that the incidence of cyclist’s palsy is highest among mountain bikers but equal among all other levels of cyclists (Patterson et al. 2003).

Time Loss

As in any professional sport, time loss due to injury can have a significant effect on a cyclist. During the time spent recovering from an injury, cardiovascular fitness is usually lost, which places the racer at a disadvantage on returning to the sport. In addition, important races for the Olympic selection process could be missed. Surprisingly, no data were found on the amount of time that is lost because of various injuries sustained in competitive cycling.

Clinical Outcome

No data exist regarding the long-term or residual effects of injuries occurring during competitive cycling–related injuries.

Economic Cost

The economic cost of an injury can vary dramatically according to the severity and location of the trauma. No data exist on the economic cost to a racer.

What Are the Risk Factors?

Although it is believed that such factors as skill, sex, previous injury, and concentration may relate to the risk of cycling injury, there are currently no studies that have tested these factors.

What Are the Inciting Events?

During training, racer accidents are unpredictable. Most often, injuries sustained by competitive cyclists while outside competition are caused by collisions with motor vehicles. During competition, racer accidents can be caused by poor road or trail conditions, collision with a race-related automobile or motorcycle, or direct bicycle-to-bicycle contact. However, no data exist on the types or frequencies of events that lead to accidents and subsequent injury.

It is currently thought that bike fit, or the relative positioning of the rider's contact points to the bicycle (feet, pelvis, hands), has potential effects on the likelihood of injury. However, no such data exist.

Injury Prevention

The use of a helmet is the most effective means of preventing bicycle-related head and facial injuries during recreational cycling (Rivera et al. 1994; Pitt et al. 1994; Carr et al. 1995). However, helmets have only recently been required for competitive cyclists. In the United States, helmet use has been mandatory during competition since 1986. And in Europe the competitive cyclist was free to race without a helmet until 2003. While the data on the efficacy of wearing a helmet during competition are sparse, a significant decline has been reported in race-related head injuries in the United States (McLennan et al. 1988; Runyan et al. 1991; Chow et al. 1993) since the advent of the helmet law. No such data are available for Europe. But, since competitive cyclists spend the majority of the time training on the open roads, outside competition (where the helmet law does not apply), it is also important to study compliance with the helmet rule.

Further Research

The epidemiology literature on cycling injuries is greatly lacking. There are few prospective studies that provide descriptive information on rate of injury, injury location, environmental location, injury onset, chronometry, injury type, time loss, clinical outcome, economic cost, or the risk factors associated with injury susceptibility. Similarly, studies on preventive measures are sparse.

This chapter has reviewed the literature, limited as it may be, on injuries among cyclists competing at the Olympic level. It is clear that a need exists for larger-scale observational and intervention studies investigating the distribution and determinants of injuries encountered during competitive cycling.

One area, in particular, with a large deficit of knowledge regarding injury is in the field of cycling biomechanics. Because of the high incidence rate of overuse injuries, it is clear that further research is needed to study the clinical incidence of overuse cycling injuries and related risk factors and inciting events.

References

Bassett, F.H. III, Soucacos, P.N. & Carr, W.A. (June 1978) AAOS symposium on the athlete's knee, Hilton Head, SC.

Boyd, T.F., Neptune, R.R. & Hull, M.L. (1997) Pedal and knee loads using multi-degree-of-freedom pedal platform in cycling. *Journal of Biomechanics*, **30**(5), 505–511.

Brogger-Jensen, T., Hvass, I. & Bugge, S. (1990) Injuries at the BMX Cycling European Championships, 1989. *British Journal of Sports Medicine* **24**(4), 269–270.

Burke E.R. (1986) *Science of Cycling.* Human Kinetics, Champaign, IL.

Callaghan, M.J. & Jarvis, C. (1996) Evaluation of elite British cyclists: the role of the squad medical. *British Journal of Sports Medicine* **30,** 349–353.

Carmont, M.R. (2008) Mountain biking injuries: a review. *British Medical Bulletin*, **85,** 101–112.

Chevalier, J.M., Megret A., L'Hoste, P., and Rousselet, M.C. (1990) A top level cyclists's pathology: external iliac arterial endofibrosis, *Techniques Chirurgicales: Chirugie Thoracique et Vasculaire*. 35–38.

Chow, T.K., Bracker, M.D. & Ungersma, J. (1993) Acute injuries from mountain biking. *Western Journal of Medicine*, **159,** 145–148.

Chow, T.K. & Kronisch, R.L. (2002) Mechanism of injury in competitive off road bicycling. *Wilderness and Environmental Medicine* **13**(1), 27–31.

Delaney, D.P. & Carr, M.C. (2005) Urethral strictures incident to BMX racing. *Urology* **65**(4), 798.

Dettori, N.J. & Norvell, D.C. (2006) Non-traumatic bicycle injuries: a review of the literature. *Sports Medicine*, **36,** 7–18.

Gassner, R.J., Hacke, W., Tuli, T., Fink, C. & Waldhart, E. (1999) Differential profile of facial injuries among mountain bikers compared to bicyclists. *Journal of Trauma* **47**(1), 50–54.

Hannaford, D.R., Moran, G.T. & Hlavac, H.F. (1988) Video analysis and treatment of overuse knee injuries in cycling: a limited clinical study. *Clinical Podiatry Medicine and Surgery,* **3**(4), 671.

Holmes, J.C., Pruitt, A.L. & Whalen, N.J. (1995) In: *The Lower Extremity and Spine in Sports Medicine*, 2nd ed. (Nicholas, J.A., & Hershman, E.B., eds.), Mosby, St. Louis, pp. 1559–1576.

Holmes, J.C., Pruitt, A.L. & Whalen, N.J. (1991) Cycling overuse injuries. *Cycling Science,* **3**(2), 11.

Kronisch, R.L., Chow, T.K., Simon, L.M. & Wong, P.F. (1996) Acute injuries in off-road bicycle racing. *American Journal of Sports Medicine*, **24**(1), 88–93.

Kronisch, R.L. & Rubin, A.L. (1994) Traumatic injuries in off road bicycling. *Clinical Journal of Sports Medicine*, **4,** 240–244.

Kronisch, R.L., Pfeiffer, R.P. & Chow, T.K,(1996) Acute injuries in cross-country and downhill off-road bicycle racing. *Medicine and Science in Sports & Exercise*, **28**(11), 1351–1355.

Kronisch, R.L., Pfeiffer, R.P., Chow, T.K. & Hummel, C.B. (2002) Gender differences in acute mountain bike racing injuries. *Clinical Journal of Sports Medicine,* **12**(3), 158–164.

Kronisch, R.L. & Pfeiffer, R.P. (2002) Mountain biking injuries: an update. *Sports Medicine* **32**(8), 523–537.

McLennan, J.G., McLennan, J.C. & Ungersma, J. (1988) Accident prevention in competitive cycling. *American Journal of Sports Medicine*, **16**(3), 266–268.

Olympic Movement (2008). Official website of the Olympic Movement. URL http://www.olympic.org/uk/index_uk.asp

Patterson, J.M., Jaggars, M.M. & Boyer, M.I. (2003) Ulnar and median nerve palsy in long distance cyclists: a prospective study. *American Journal of Sports Medicine,* **31**(4), 585–589.

Pfeiffer, R.P. (1993) Injuries in NORBA pro/elite category off-road bicycle competitors. *Cycling Science,* **5,** 21–24.

Pfeiffer, R.P. (1994) Off-road bicycle racing injuries—the NORBA pro/elite category. *Clinics in Sports Medicine,* **13,** 207–218.

Pfeiffer, R.P. & Kronisch, R.L. (1995) Off-road cycling injuries: an overview. *Sports Medicine*, **19**(5), 311–325.

Pitt, W.R., Thomas, S. & Nison, J. (1994) Trends in head injuries among child bicyclists. *British Medical Journal,* **308,** 177.

Richardson, D. (2007) *Ryan Cox and Iliac Artery Endofibrosis.* URL http://Velonews.com [accessed on August 8, 2007]

Rivera, F.P., Thompson, D.C. & Thompson, R.S. (1994) The Seattle children's bicycle helmet campaign: changes in helmet use and head injury admissions. *Pediatrics,* **93**(4), 567–569.

Runyan, C.W., Earp, J.L. & Reese, R.P. (1991) Helmet use among competitive cyclists. *American Journal of Preventive Medicine,* **7,** 232–236.

Sanderson, D.J. (1990) The biomechanics of cycling shoes, *Cycling Science,* **2**(3), 27.

Taylor, A.J., Tennant, W.G., Batt, M.E. & Wallace, W.A. (1997) Traumatic occlusion of the external iliac artery in a racing cyclist: a cause of ill defined leg pain. *British Journal of Sports Medicine*, **31**(2), 155–156.

Thompson, D.C. & Patterson, M.Q. (1998) Cycle helmets and the prevention of injuries: recommendations for competitive sport. *Sports Medicine*, **25**(4), 213–219.

Thompson, M.J. & Rivara, F.P. (2001) Bicycle related injuries. *American Family Physician,* **63**(10), 14.

Wesson, D., Spence, L., Hu, X. & Parkin, P. (2000) Trends in bicycling related head injuries in children after implementation of a community-based bike helmet campaign, *Journal of Pediatric Surgery,* **35**(5), 688–689.

Wilber, C.A., Holland, G.J., Madison, R.E., Loy, S.F. (1995) An epidemiological analysis of overuse injuries among recreational cyclists, *Int. J. Sports Med*, **16**(3), 201–206

Chapter 9

Equestrian

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Introduction

In 682 B.C., a chariot race was run at Greece's 25th Olympiad, marking the earliest recorded date in equestrian sports history. From that early beginning, both team and individual equestrian events developed and in the modern era, equestrian as a competitive sport first began in 1868 at the Royal Dublin Horse Show. By the latter part of the 19th century, there were regular international events and competitions. Although individual show jumping was part of the Paris Olympics of 1900, the full equestrian program of dressage, show jumping, and 3-day eventing was introduced at the Stockholm Olympics in 1912, see Figure 9.1.

Very quickly, the need for standardized international rules was recognized, and in May 1921 delegates from 10 national equestrian organizations met in Lausanne, Switzerland, to discuss the formation of an international federation in order to harmonize regulations governing the sport. The Fédération Equestre Internationale (FEI), founded in the same year remains the international body governing equestrian sport recognized by the International Olympic Committee (IOC). The FEI is the sole controlling authority for all international events in dressage, jumping, eventing, driving, endurance, vaulting, reining and para-equestrian. It establishes the regulations and approves the equestrian programs at championships, continental and regional games as well as the Olympic games.

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Figure 9.1 Olympic equestrian sport—3-day event. © IOC / Yasuo YUBA.

Equestrian Sports in the Ancient Olympics

The ancient Olympics were rather different from the modern Games. Beginning in 776 B.C. with a single foot race, these games became the preeminent games in ancient times. Equestrian sports were introduced at the 25th Olympiad in 682 B.C. The original stadium was too small for the four-horse chariot race, so all horse-racing events were held at the hippodrome, adjacent to the main stadium. Over time, the events expanded to encompass both two-horse chariot and four-horse chariot races, with separate races for chariots drawn by foals. Another known Olympic event was a race between carts drawn by a team of two mules, somewhat reminiscent of the "chuck wagon" races seen at modern-day rodeos. The course for all chariot events was 12 laps around the stadium track (~9 miles). For races with single riders, the course was 6 laps around the track (~4.5 miles), and there were separate races for full-grown horses and foals. Jockeys rode without stirrups. Only wealthy people could afford to pay for the training, equipment, and feed of both the driver (or jockey) and the horses. As a result, the owner received the olive wreath of victory instead of the driver or jockey.

Equestrian Sports in the Modern Olympics

Equestrian events were first included in the modern Olympic Games in 1900 at the Paris Olympics, with individual show jumping, high jumping, and long jumping. At the 1906 IOC meeting, Baron Pierre de Coubertin, the founder of the modern Olympics, requested that a Swedish cavalry officer Count Clarence Von Rosen draft a more detailed Olympic equestrian program. This was then subsequently presented to the Olympic Congress at the Hague in 1907 and was accepted for the 1908 Games to be held in London. However, when the Organising Committee received the entries from 88 riders from 8 nations, it was overwhelmed and unable to organize the full program. Fortunately, the 1912 Games were awarded to Stockholm, and the equestrian Olympic program proposed by Count Van Rosen was readily accepted. In the autumn of 1911, the invitations were sent out to the military departments and to the National Olympic Committees. The three-day event (eventing) was limited to officer entries, but the jumping and dressage competitions were open to civilians. The first Equestrian participation at the Olympics saw 62 competitors (all military officers) from 10 nations, with 70 horses involved in the competitions. Since 1928, the six key events (team and individual competition in the three disciplines) have remained relatively constant.

From 1952 onward, equestrian sports became one of the very few Olympic events in which men and women (civilian as well as military) compete directly against one another. In team competition, teams may have any blend of male and female competitors, and are not required to have minimum numbers of either sex; countries are free to choose the best riders, irrespective of sex. Equestrian disciplines and the equestrian component of the Modern Pentathlon are also the only Olympic events that involve animals. The horse is considered as much an athlete as the human rider.

Additional events sanctioned by the FEI as international disciplines include combined driving, reining, equestrian vaulting, endurance riding, and Paralympic competitions. While these events are recognized internationally and are all part of the FEI World Equestrian games, none are yet part of the Summer Olympics, though some, such as vaulting and reining, are potentially on track to be added.

Recreational Equestrian Sports

The vast majority of horse riders are amateurs who ride for recreation. The demographics of injury at this level are largely unknown, although some information is available in specific subgroups of riders, such as professional jockeys, rodeo riders, and polo participants. (Turner & McCrory, 2002).

In broad terms, the approximate numbers of horse riders is known. In the United States, over 30 million people ride on a regular basis, with more than 2 million of these being under the age of 19 (Bixby-Hammett & Brooks 1990; Bixby-Hammett 1992; Nelson & Bixby-Hammett, 1992, Nelson et al. 1994a, Nelson et al. 1994c). In the United Kingdom, this figure is estimated to be 3 million regular participants, with one third being children. (Silver & Parry, 1991) In Australia, there are over 250,000 people actively engaged in recreational horse riding, with 74,000 registered child participants in events run by pony clubs and the Equestrian Federation of Australia (Cripps 2000).

Methods and Aims

This chapter seeks to define the scope and epidemiology of injuries seen in equestrian sports and their nature and risk factors. It must be noted that little or no specific injury information exists with regard to Olympic equestrian competition and as a result, information has been sought from the wider spectrum of equestrian sport.

The limited available data on equestrian injury are largely a reflection of the way horse riding is conducted. Namely, the sport is mostly amateur, variably supervised, and, apart from limited competitive situations, is not subject to administrative control that would enable the compilation of injury data. Injuries, especially minor injuries, are seldom reported, and there are no regulatory requirements anywhere in the world that compel formal injury notification for this sport other than in professional horseracing in some countries. This lack of detailed information is somewhat surprising, given that horse riding is one of the most popular participation sports with tens of millions of active riders in most Western countries.

Who Is Affected by Injury?

Horse racing is considered to be one of the most dangerous sports in the world, as it involves two different species functioning together as a team, with the horse being able to act autonomously and unpredictably. The fully grown horse can weigh up to 550 kg and travel at speeds of 60 km/hr, putting the rider, who is at up to 3 m above ground, at significant risk of injury (Thomas et al. 2006).

Recreational Riders

All published studies of recreational equestrian injuries report acute injuries only. Both Gierup et al. (1976) and Williams et al (1995) have reported a one-third incidence of previous injuries in riders presenting to hospital with a new acute injury, although no details were provided, nor was any exposure information to suggest that injured riders' represent the typical horse-riding population. Although numerous case series have reported specific injury occurrences, such as catastrophic head or spinal injury, the common thread missing throughout all these studies is information on exposure. (Ball et al. 2007; Gabbe et al. 2005) Similar criticisms can be made about electronic injury surveillance systems, such as the U.S. national injury surveillance system (http://www.nyssf.org/statistics1998.html) or the North American CHIRPP database (http://www.hc-sc.gc.ca/pphb-dgspsp/publicat).

Injury information from retrospective and case series studies of injuries affecting equestrian riders are summarized in Table 9.1. A review of this table provides a demographic breakdown by age and sex. where reported, and by the most frequent injures. It is important to note that in line with the majority of epidemiologic data in this sport, information is derived mostly from postal surveys, retrospective questionnaires of hospitalized patients, and hospital inpatient data (where no exposure information is recorded) and are biased toward acute injuries. Nevertheless, it can be seen that young (< 15 years) female riders predominate and that fractures are the most common injury noted.

In addition, there are articles specifically examining acute recreational equestrian participation and pediatric injuries (Grossman et al. 1978; Lloyd 1987; Bixby-Hammett & Brooks 1990; Bixby-Hammett 1992; Chitnavis et al. 1996; Moss et al. 2002; McCrory & Turner 2005). This area has been reviewed and the findings are similar findings to those found in Table 9.1 (McCrory & Turner 2005).

Professional Jockeys

Professional jockeys are a group at high risk of injury because of their occupational exposure to horses as part of training as well as competitive race situations. In the United Kingdom, the top rank of jockeys competes over 900 times per season and have the highest injury rates of any competitive sport (Turner & McCrory, Balendra 2002 et al. 2008).

Table 9.1 Retrospective and case series studies.

Study Reference	Patient Source	Total No. of Equestrian Injuries	No. of Injuries <15 yr old (% of total)	Demographics
Bernhang & Winslett (1983)	Horse Shows Association survey, United States	290	62 (21%)	85% female 34% falls 15% fractures
Bernhang & Winslett (1983)	Pony club survey, United States	31	19 (61%)	No analysis performed
Barone and & Rodgers (1989a)	Hospital admissions, United States	136	NS	76% female 75% falls 62% fractures
Sahlin (1990)	Pediatric hospital, Norway	23	23 (100%)	90% female 60% falls 50% fractures
Bixby-Hammett & Brooks 1990)	National Electronic Injury Surveillance System, United States	167,578	48,822 (29%)	65% female
Buckley et al. (1993)	National injury data-base, New Zealand	827	315 (38%)	74% female 46% fractures
Nelson et al. (1994b)	Postal survey, United States	589 (27% of total surveyed)	46 (8%)	Injury rate, 0.4/per 1,000 hr
Sorensen et al. (1996)	Paediatric Hospital data, Sweden	516		95% female 27% fractures Injury rate, 14/1000 hrs
Campbell-Hewson et al. (1999)	Pediatric emergency department, United Kingdom	41	41 (100%)	95% female 66% falls 26% fractures
Ghosh et al. (2000)	National Pediatric Trauma Registry, United States	720	276 (38%)	62% female 64% falls 35% fractures
Cripps 2000)	Australian Bureau of Statistics data, Australia	64		
Moss et al. (2002)	Emergency department, United Kingdom	260 (10% of all sports injuries)	62 (23%)	80% female 80% falls 60% fractures
Ball et al. (2007)	Questionnaire of emergency patients Canada	151	Not stated	Sex not stated 54% Chest injuries

Where Does Injury Occur?

Anatomical Location

Injuries to the extremities comprise the largest group of injuries. They are predominantly soft-tissue injuries and long-bone fractures (Watt & Finch 1996; Lim et al. 2003) Patients with such injuries are not routinely admitted to the hospital, and they may be underrepresented in published studies. Patients with equestrian-related head injuries are typically admitted to hospital, and hence are recorded more accurately. Head injuries are responsible for the majority of serious equestrian injuries and deaths. (Bixby-Hammett 1983, 1987, 1992, 2006; Lloyd 1987; Silver & Parry 1991; Nelson & Bixby-Hammett 1992; Nelson et al. 1994c; Silver 2002) Such injuries are almost invariably related to falls. Injuries to the thorax, abdomen, and pelvis are also often severe and account for a smaller but substantial number of hospitalizations (Bixby-Hammett 1983, 1987, 1992, 2006).

There are very few published studies that record the anatomical location of injury in any detail. Ball et al. (2007), in a Canadian study of 151 surgical patients, reported that 54% of injuries were to the chest, 48% to the head, 22% to the abdomen and 17% to the extremities. Although these figures seemingly contradict other studies, they reflect the nature of the study population. Studies that have looked at rates of acute injuries in professional jockeys have found that soft-tissue injuries are the most common injuries overall (varying between 32% and 84% of injuries), whereas upper-limb fractures are the most common significant injury, followed by concussion and upper-limb joint dislocation. (Press et al. 1995; Turner & McCrory 2002; McCrory et al. 2006; Balendra et al. 2007).

Environmental Location

The majority of equestrian injuries occur during leisure riding rather than in competition (Whitlock et al. 1987; MMWR 1996) Unfortunately, no published studies provide any specific breakdown of either the proportion of leisure-related injuries or more precise information in this regard. Equestrian injuries tend to occur when the rider is mounted (Barone & Rodgers 1989; Nelson & Bixby-Hammett 1992; Hobbs et al. 1994; Nelson et al. 1994c), during riding lessons (Bixby-Hammett 1987), on farms, or in paddocks.

When Does Injury Occur?

Injury Onset

As noted previously, the majority of published studies report little information regarding injury onset, as most, if not all, reported injuries are acute injuries presenting to hospital emergency departments.

Chronometry

One study reports injuries occurring more frequently during school holidays (Silver & Parry 1991) and on weekends; however, this more likely represents the most frequent type of riding conducted rather than suggests that holidays represent a particular threat of injurious situations.

What Is the Outcome?

Injury Type

There are no data available from prospective studies or where the exposure incidence is known that enable injury-rate calculation. The published retrospective and case series studies are outlined in Table 9.1 and are presented as a percentage of total injuries. Although the broad categories of anatomical injuries are commonly reported, the widely varied methods make comparison impossible.

Furthermore, in studies (such as in professional jockeys) in which detailed injury information is prospectively recorded, there is enormous variation in the same injury across different countries. This is shown in Table 9.2, illustrating differences in fracture rates. It is speculated that this disparity reflects intrinsic differences (e.g., low bone density and increased fracture risk) between individuals rather than a difference in horse-riding techniques (McCrory et al. 2006). In the same study, the most common type of injury was a soft-tissue injury and the frequency varied between 32% and 84% of all

Table 9.2 Fractures by race category and country of origin in professional jockeys

Country	Flat racing		Jumps Racing	
	Fractures as % of Total Falls	Fractures per 100,000 Rides	Fracture as % of Total Falls	Fractures per 100,000 Rides
France	19.6	60.5	6.60	603.2
Ireland	9.8	36.1	3.37	159.9
Great Britain	3.3	14.6	2.51	169.8

Data are from McCrory et al. (2006).

injuries depending on the country of origin of the injured jockey.

Time Loss

Limited published information exists, and the time lost reported in published studies generally refers to either chronic injuries or those severe enough to warrant hospital presentation. There are no prospective data available for acute injuries.

There is one published paper detailing time lost from racing and insurance payments to professional jockeys in the United Kingdom (Turner et al. 2008) The findings are summarized in Table 9.3. No other published data exist for recreational riding and time loss.

Clinical Outcome

No published prospective information exists. There are a variety of case series and retrospective questionnaire-based studies reporting long-term outcome and time lost from equestrian injuries. In general terms, all of these papers suffer from selection bias, given the population from which injuries are obtained in addition to the methodologic limitations of the study design (Nelson & Bixby-Hammett 1992; Giebel et al. 1993; Nelson et al. 1994c; Campbell-Hewson et al. 1999; Ghosh et al. 2000; Sorli 2000; Dekker et al. 2003, 2004).

The same is true with catastrophic spinal cord injuries—data from hospital spinal cord services have been published (Roe et al. 2003). Given the relatively small numbers of these injuries and the selection bias inherent in hospital data, the strength of any preventative recommendations (e.g., body protectors) in this setting is limited.

In professional sport, specific information exists as to career-ending injuries; however, it must be understood that these represent the minority of injuries to professional jockeys (Balendra et al. 2008) In the published study, 45 such injuries were recorded over a 15-year time frame. The distribution of these injuries in shown in Figure 9.2.

Various case series and recommendations have been reported detailing catastrophic head and spinal injury from equestrian participation (Ingermarson et al. 1989; CDC 1990; Nicholl et al. 1991, 1995; Silver & Parry 1991; Buckley et al. 1993; Christey et al. 1994; Bond et al. 1995; MMWR 1996; Committee on Quality Improvement 1999; Cripps 2000; Moss et al. 2002; Silver 2002). In general, the rate of fatal head injuries from horse riding is relatively low both in general terms and in comparison with other sports (Nicholl et al. 1991, 1995). In one of the few prospective estimates, this horse riding–related mortality risk was put at 0.08 per 100,000 population (Cripps 2000) This risk estimate includes all age groups.

Table 9.3 Days off of racing in professional jockeys in the United Kingdom

Days off Racing (maximum = 546)	No. of Claims	% of Total
1–7	214	16.1
8–14	213	16.1
15–21	158	11.9
22–28	132	9.9
29–60	317	23.9
61–90	107	8.0
91–120	60	4.5
121–150	34	2.5
151–180	22	1.7
181–365	38	2.9
366–546	33	2.5
Total	1,328	100.0%

Data are from Turner et al. (2008).

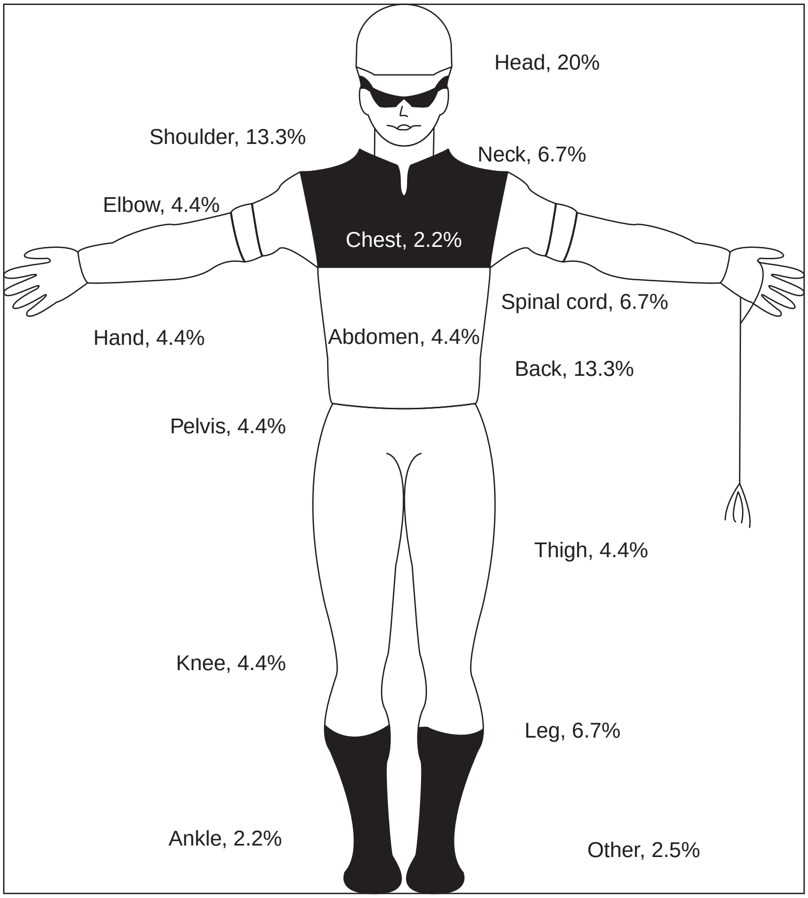

Figure 9.2 Anatomical site of injury in professional jockeys.

Economic Cost

The only study examining the economic cost of injury (or at least insurance costs for injuries) was in professional jockeys in the United Kingdom (Balendra et al. 2008). In that study, approximately 1,328 injuries were reported to the insurer during the 11-year period from 1996 to 2006, and the total cost of these injures was almost £4,500,000 (approximately US$8.9 million). A large percentage of the injuries were minor ones and received relatively small payouts. The most common injuries suffered by jockeys were fractures, more specifically, clavicle fractures. However, dislocations were the most serious injury, accounting for the longest time out of racing and the highest payouts. No breakdown was reported in terms of the nature of treatment required or the indirect economic costs of injury.

What Are the Risk Factors?

Intrinsic Factors

There are relatively few intrinsic factors that predispose a rider to injury. with none that have been validated scientifically. In general, a rider requires a sense of balance, reasonable physical fitness, and alertness to ride. Clearly, anything that impairs these functions would be a contraindication to riding. In the same manner, avoidance of alcohol and drugs that may impair riding should be mandatory.

Horse-riding experience has been proposed with the recommendation that a minimum of 100 hours of riding experience is required before injury reduction occurs (Mayberry et al. 2007) The evidence for this was based on a mail survey of pony clubs in the United States, in which novice riders' reported greater injury rates than more advanced riders. However, no exposure data were collected. The broad recommendation, however, that injury prevention efforts need to focus on novices seems reasonable.

Extrinsic Factors

There are many potential factors that have an impact on the athlete and injury prevention, such as protective equipment, coaching, rules, and environmental risks. However, none of these have been analytically studied in equestrian sport.

What Are the Inciting Events?

Although falling from horses or being kicked are the most familiar mechanisms of injury, horses can also inflict injuries by biting, pulling, kicking the rider, standing or rolling on the rider, and hitting the rider with a sudden movement of the head (Regan et al. 1991). It is also noted that in riders, approximately 15% of equestrian injuries occur during nonriding activities, such as grooming, feeding, handling, shoeing, and saddling (Bixby-Hammett 1987; Barone & Rodgers 1989; Hobbs et al. 1994; McCrory & Turner 2005)

No published information exists regarding the specific activities being performed at the time of the injury, with the possible exception of where an injury results from a collision between horse and car while road riding (Silver & Parry 1991).

Injury Prevention

There are no published data on injury prevention that have been subjected to formal analysis. The use of other protective equipment, like body protectors and safety stirrups has been made compulsory in recent years so as to reduce the incidence of injuries; however, the efficacy of many of these interventions has never been validated (Turner & McCrory 2002; Ceroni et al. 2007).

Protective equestrian helmets are widely recommended. Such helmets need to be certified to an appropriate material testing standard, and a variety of impact standards exist in different countries. There have been no formal prospective or controlled studies conclusively demonstrating a benefit or even that the current helmet test standards are adequate to prevent head injury (Watt & Finch, 1996). There is some anecdotal evidence, however, suggesting a benefit for helmet use in preventing or lessening the severity of head injuries (Nelson & Bixby-Hammett 1992; Bond et al. 1995). Similarly, the benefits of other safety equipment, such as body protectors and safety-release stirrups remain unproven.

Most equestrian organizations have regulations governing the conduct of the sport and include specific equestrian safety issues. In professional horse racing, and to a lesser extent in amateur racing, there are strict licensing requirements, supervision of race courses, veterinary assessment of horses, medical assessment of jockeys, and enforcement of riding and safety rules. Pony clubs and similar groups in the pediatric age group have specific safety standards for supervisors and riders, and strict requirements for helmet use.

Further Research

The major challenges facing equestrian sports is the accurate understanding of injury rates across a wide spectrum of sports participation coupled with the formal scientific demonstration that the various proposed injury-prevention measures are effective. Ideally, this should be performed before they are implemented or promoted. In addition, the barriers to the adoption of injury-prevention measures should be studied.

Given the high participation in organized instructional programs such as a pony club, an assessment of the effectiveness of rider (and supervisor) training should be undertaken. Rider and public education may assist in informing riders about specific risks with riding and, hence, alter behavior to avoid dangerous situations as well as encouraging the use of protective equipment. Although laudable, such campaigns need to be validated against defined outcomes (Thompson 1994; Northey 2003).

Ensuring that riding instructors are certified, experienced, and have a good knowledge of horses are all reasonable measures, although no formal analysis has correlated injuries with instruction, and any certification needs to be formally evaluated.

Horse selection may have a role, whereby instructors can match suitable horses with the level of rider experience. As with all primary prevention measures, the efficacy depends on both whether the regulations are enforced and whether the safety requirements are themselves effective (Mayberry et al. 2007).

Some authors have suggested specific neurologic contraindications to riding, including unstable spinal cord lesions, permanent sequelae from head injury, and repeated painful injury to the cervical and lumbar spine (Bixby-Hammett & Brooks 1990). None of these have been validated prospectively, and would need to be individually assessed.

Horse behavior is also a significant factor in many equestrian injuries. In U.S. Pony Club surveys, it has been estimated that up to 80% of injuries resulted from the behavior of the horse (Bixby-Hammett 1987). Although horses are by their very nature unpredictable, some basic principles are important and may be taught as part of basic horse-riding instruction. Warm-up procedures for the horse, rider training, supervisor awareness of aberrant horse behavior, specific instruction in the safe approach to horses, and avoidance of situations in which other animals or vehicles may frighten a horse, have all been proposed but not evaluated (Watt & Finch 1996). Specific "tuck-and-roll" techniques if unmounted have been suggested as a means, albeit unproven, of reducing injuries in falls.

Appropriate and well-maintained equipment (e.g., tack or saddlery) is important to prevent falls. The checking of equipment as part of a premounting and predismounting routine is critical, although it has not been rigorously assessed. Similarly, appropriate clothing, such as riding boots and gloves are important.

With the majority of equestrian injuries happening during unsupervised leisure riding, the likelihood of preventing injury is reduced. Rider-education campaigns to ensure adequate training, maintenance and inspection of equipment, and wearing appropriate clothing and helmets may all assist in reducing injuries. Because there is so little knowledge of injury demographics or the efficacy of prevention countermeasures in this field, it is likely that injuries will continue to occur.

References

Balendra, G., Turner, M. & McCrory, P. (2008) Career ending injuries to professional jockeys in British horse racing 1991–2005. *British Journal of Sports Medicine* **42,** 22–24.

Balendra, G., Turner, M., McCrory, P. & Halley, W. (2007a) Injuries in amateur horse racing (point to point racing) in Great Britain and Ireland during 1993–2006. *British Journal of Sports Medicine* **41**, 162–166.

Ball, C.G., Ball, J. E., Kirkpatrick, A.W. & Mulloy, R.H. (2007) Equestrian injuries: incidence, injury patterns, and risk factors for 10 years of major traumatic injuries. *American Journal of Surgery* **193**, 636–640.

Barone, G.W. & Rodgers, B.M. (1989) Pediatric equestrian injuries: a 14 year review. *Journal of Trauma* **29**, 245–247.

Bernhang, A. & Winslett, G. (1983) Equestrian injuries. *Physician and Sportsmedicine* **11**, 90–97.

Bixby-Hammett, D.M. (1983) Head injuries in equestrian sports. *Physician and Sportsmedicine* **11**, 82–86.

Bixby-Hammett, D.M. (1987) Accidents in equestrian sports. *American Family Physician* **36**, 209–214.

Bixby-Hammett, D.M. (1992) Pediatric equestrian injuries. *Pediatrics* **89**, 1173–1176.

Bixby-Hammett, D.M. (2006) Horse-related injuries and deaths in North Carolina, 1995–1999. *North Caroline Medical Journal* **67**, 161–162.

Bixby-Hammett, D. & Brooks, W.H. (1990) Common injuries in horseback riding: a review. *Sports Medicine* **9**, 36–47.

Bond, G. R., Christoph, R. A. & Rodgers, B. M. (1995) Pediatric equestrian injuries: assessing the impact of helmet use. *Pediatrics* **95**, 487–489.

Buckley, S., Chalmers, D. & Langley, J. (1993) Injuries due to falls from horses. *Australian Journal of Public Health* **17**, 269–271.

Campbell-Hewson, G.L., Robinson, S.M. & Egleston, C.V. (1999) Equestrian injuries in the paediatric age group: a two centre study. *European Journal of Emergency Medicine* **6,** 37–40.

CDC (1990) Injuries associated with horseback riding—United States 1987/8. *Journal of the American Medical Association* **264**, 18–19.

Ceroni, D., De Rosa, V., De Coulon, G. & Kaelin, A. (2007) The importance of proper shoe gear and safety stirrups in the prevention of equestrian foot injuries. *Journal of Foot and Ankle Surgery* **46**, 32–39.

Chitnavis, J.P., Gibbons, C.L., Hirigoyen, M., Lloyd Parry, J. & Simpson, A.H. (1996) Accidents with horses: what has changed in 20 years? *Injury* **27**, 103–105.

Christey, G.L., Nelson, D. E., Rivara, F.P., Smith, S.M. & Condie, C. (1994) Horseback riding injuries among children and young adults. *Journal of Family Practice* **39**, 148–152.

Committee on Quality Improvement, American Academy of Pediatrics. (1999) The management of minor closed head injury in children. *Pediatrics* **104,** 1407–1415.

Cripps, R.A. (2000) Horse-related injury in Australia. *Australian Injury Prevention Bulletin* **24,** 1–20.

Dekker, R., Groothoff, J.W., Eisma, W.H. & Ten Duis, H.J. (2003) [Clinical treatment of equestrian injuries in Groningen, 1990–1998: serious long-term effects]. *Nederlands Tijdschrift voor Geneeskunde* **147**, 204–208.

Dekker, R., Van Der Sluis, C.K., Kootstra, J., Groothoff, J.W., Eisma, W.H. & Duis, H.J. (2004) Long-term outcome of equestrian injuries in children. *Disability and Rehabilitation* **26**, 91–96.

Gabbe, B.J., Finch, C.F., Cameron, P.A. & Williamson, O.D. (2005) Incidence of serious injury and death during sport and recreation activities in Victoria, Australia. *British Journal of Sports Medicine* **39**, 573–577.

Ghosh, A. K., Scala, C. D., Drew, C., Lessin, M. & Feins, N. (2000) Horse-related injuries in pediatric patients. *Journal of Pediatric Surgery* **35**, 1766–1770.

Giebel, G., Braun, K. & Mittelmeier, W. (1993) [Equestrian accidents in children]. *Chirurgie* **64**, 938–947.

Gierup, J., Larsson, M. & Lennqvist, S. (1976) Incidence and nature of horse riding injuries. *Acta Chirurgica Scandinavica* **142**, 57–61.

Grossman, J.A., Kulund, D.N., Miller, C.W., Winn, H.R. & Hodge, R.H., Jr. (1978) Equestrian injuries: results of a prospective study. *Journal of the American Medical Association* **240**, 1881–1882.

Hobbs, G.D., Yealy, D.M. & Rivas, J. (1994) Equestrian injuries: a five-year review. *Journal of Emergency Medicine* **12**, 143–145.

Ingermarson, H., Grevsten, S. & Thoren, L. (1989) Lethal horseriding injuries. *Journal of Trauma* **29**, 25–30.

Lim, J., Puttaswamy, V., Gizzi, M., Christie, L., Croker, W. & Crowe, P. (2003) Pattern of equestrian injuries presenting to a Sydney teaching hospital. *Australian and New Zealand Journal of Surgery* **73**, 567–71.

Lloyd, R.G. (1987) Riding and other equestrian injuries: considerable severity. *British Journal of Sports Medicine* **21**, 22–24.

Mayberry, J.C., Pearson, T.E., Wiger, K.J., Diggs, B.S. & Mullins, R.J. (2007) Equestrian injury prevention efforts need more attention to novice riders. *Journal of Trauma* **62**, 735–739.

McCrory, P. & Turner, M. (2005) Equestrian injuries. *Medicine and Sport Science* **48**, 8–17.

McCrory, P., Turner, M., Lemasson, B., Bodere, C. & Allemandou, A. (2006) An analysis of injuries resulting from professional horse racing in France during 1991–2001: a comparison with injuries resulting from professional horse racing in Great Britain during 1992–2001. *British Journal of Sports Medicine* **40**, 614–618.

MMWR (1996) Horseback riding associated traumatic brain injury—Oklahoma 1992–1994. *MMWR,* 45, 209–211.

Moss, P.S., Wan, A. & Whitlock, M.R. (2002) A changing pattern of injuries to horse riders. *Emergency Medicine Journal* **19**, 412–414.

Nelson, D., Rivara, F. & Condie, C. (1994a) Helmets and horseback riders. *American Journal of Preventive Medicine* **10**, 15–19.

Nelson, D., Rivara, F., Condie, C. & Smith, S. (1994b) Injuries in equestrian sports. *Physician and Sportsmedicine* **22**, 53–60.

Nelson, D.E. & Bixby-Hammett, D. (1992) Equestrian injuries in children and young adults. *American Journal of Disability and Childhood* **146**, 611–614.

Nelson, D.E., Rivara, F.P., Condie, C. & Smith, S.M. (1994c) Injuries in equestrian sports. *Physician and Sportsmedicine* **22**, 53–60.

Nicholl, J., Coleman, P. & Williams, C. (1991) *Injuries in Sport and Exercise.* Medical Care Research Unit, Department of Public Health Medicine, Sheffield University Medical School, Sheffield, UK,.

Nicholl, J., Coleman, P. & Williams, B. (1995) The epidemiology of sports and exercise related injury in the United Kingdom. *British Journal of Sports Medicine* **29**, 232–238.

Northey, G. (2003) Equestrian injuries in New Zealand, 1993–2001: knowledge and experience. *New Zealand Medical Journal* **116**, U601.

Press, J.M., Davis, P.D., Wiesner, S.L., Heinemann, A., Semik, P. & Addison, R.G. (1995) The national jockey injury study: an analysis of injuries to professional horse-racing jockeys. *Clinical Journal of Sports Medicine* **5**, 236–240.

Regan, P., Roberts, J., Feldberg, L. & Roberts, A. (1991) Hand injuries from leading horses. *Injury* **22**, 124–126.

Roe, J.P., Taylor, T.K., Edmunds, I.A., Cumming, R.G., Ruff, S.J., Plunkett-Cole, M.D., Mikk, M. & Jones, R. F. (2003) Spinal and spinal cord injuries in horse riding: the New South Wales experience 1976–1996. *Australian and New Zealand Journal of Surgery* **73**, 331–334.

Sahlin, Y. (1990) Sports accidents in childhood. *British Journal of Sports Medicine* **24**, 40–44.

Silver, J. & Parry, J. (1991) Hazards of horse riding as a popular sport. *British Journal of Sports Medicine* **25**, 105–110.

Silver, J.R. (2002) Spinal injuries resulting from horse riding accidents. *Spinal Cord* **40,** 264–271.

Sorensen, L., Larsen, S.E. & Rock, N.D. (1996) The epidemiology of sports related injuries in school-aged children. *Scandinavian Journal of Sports Medicine* **6**, 281–286.

Sorli, J.M. (2000) Equestrian injuries: a five year review of hospital admissions in British Columbia, Canada. *Injury Prevention* **6**, 59–61.

Thomas, K.E., Annest, J.L., Gilchrist, J. & Bixby-Hammett, D.M. (2006) Non-fatal horse related injuries treated in emergency departments in the United States, 2001–2003. *British Journal of Sports Medicine* **40**, 619–626.

Thompson, D. C. (1994) Do bicycle helmets prevent head injury in children? *Clinical Journal of Sport Medicine* **4**, 199.

Turner, M., Balendra, G. & McCrory, P. (2008) Payments to injured professional jockeys in British horse racing (1996–2006). *British Journal of Sports Medicine* **42,** 763–766.

Turner, M. & McCrory, P. (2002) Horseracing injuries: injuries resulting from professional horseracing in Great Britain and Ireland during the period 1992–2000. *British Journal of Sports Medicine* **36**, 403–409.

Watt, G. M. & Finch, C. F. (1996) Preventing equestrian injuries: locking the stable door. *Sports Medicine* **22**, 187–197.

Whitlock, M. R., Whitlock, J. & Johnston, B. (1987) Equestrian injuries: a comparison of professional and amateur injuries in Berkshire. *British Journal of Sports Medicine* **21**, 25–26.

Williams F. & Ashby K. (1995) Horse related injuries, HAZARD Edition 23 (June 1995). Melbourne, Australia, Victorian Injury Surveillance System/ Monash University Accident Research Centre, 1–13.

Chapter 10

Fencing

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Introduction

Fencing is one of only four sports to have been included in every Olympiad of the modern era. Olympic competition has basically consisted of events for men in the standard three weapons since its inception (individual foil and sabre from 1896, individual epee from 1900; team epee and sabre from 1906; team foil from 1920) (Fencing 2008). The first event for women (individual foil) was introduced in 1924, with a team foil event being added in 1960. Individual and team épée for women were included in the Olympic program for the first time in 1996 with women's saber added in 2004. The martial origins of fencing and the use of weaponry in individual combat impart the impression of high risk to modern competitive fencing. The purpose of this chapter is to examine the veracity of this belief by evaluating the extant literature on fencing-related injury. The focus was on data-based studies, although case reports and case series were included for a fuller understanding of clinical outcomes, particularly for catastrophic and complicated injuries. Overall, the paucity of well-designed, data-driven studies was evident.

Who Is Affected by Injury?

A summary of studies reporting injury rates in fencing is presented in Table 10.1. Although the percentage of fencers recorded as injured in specific competitions (20–27.5%; Majorano & Cesario 1991; Naghavi 2000) or self-reported as sustaining an injury in their fencing careers (59–77.8%; Nye 1967; Carter et al. 1993) appears high, exposure-based injury rates, especially for time-loss injuries (i.e., those significant enough to necessitate an athlete withdrawing from competition) indicate that the majority of fencing injuries are minor. For example, in a review of 15 years of sports-insurance data in Germany, Raschka et al. (1999) estimated an injury rate of 0.12 per 1,000 persons/yr for fencing, which was the lowest, with aikido, of eight combat sports analyzed. Studies in Table 10.1 indicate consistent findings of a time-loss rate of 0.0 to 0.3 per 1,000 athlete exposures (AE) across a wide variety of competition and training settings. By comparison, soccer and basketball have been found to have ~50 times and 31 times higher rates of time loss from competition because of injury, respectively, than fencing (Harmer 2008a).

Where Does Injury Occur?

Anatomical Location

The percent distribution of injury by anatomical location is presented in Table 10.2. Although several studies have found that the highest proportion of injuries involved the wrist, hand, and fingers (range, 54.6–61.3%), the majority of research has shown the lower extremities to be the most common site of injury (mean = 59%; range, 42.9–77.3%), specifically

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Table 10.1 Comparison of fencing injury rates.

Study	Design	Data Collection	Data Source (Duration of Study)	Location	No. of Participants	No. of Injuries	Injury Rate		
							Overall per 1,000 AE[a]	Time-loss per 1,000 AE[b]	Other
Weightman & Browne (1975)	P	Q	Community fencing clubs (1 yr)	England	Clubs = 18	25	—	—	0.42[a,c]
Graham & Bruce (1977)	P	Q	University fencing teams (1 yr)	USA	F = 64	0	—	0	0.0[b,d]
Roi & Fasci (1986)	P	DM	Regional youth competitions (1 yr)	Italy	n = 358	11	2.1	0	3.1[a,d]
Roi & Fasci (1988)	P	DM	Regional competitions (1 yr)	Italy	n = 1365	58	4.3	0.22	0.2[b,d]
Lanese et al. (1990)	P	DM/I	University fencing team (1 yr)	USA	M = 18	5	—	—	1.0[b,c]
					F = 6	3	—	—	1.8[b,c]
Majorano & Cesario (1991)	P	DM	National competition (1 competition)	Italy	n = 801	100	—	—	0.25[b,d]
Gambaretti et al. (1992)	P	Q	Milan-area fencers (1 yr)	Italy	n = 178	49 (competition only)	—	—	27.5[a,e]
Naghavi (2000)	P	DM	International Junior competition (1 competition)	Iran	M = 155	31	25.4	0.0	20.0[a,d]
Harmer (2007)	P	DM	Veterans World Championships (5 yr)	International	n = 1398	2	—	0.2	0.1[b,d]
					M = 892	2	—	0.33	0.2[b,d]
					F = 506	0	—	0.0	0.0[b,d]
Harmer (2008a)	P	DM	National competitions (5 yr)	United States	n = 78,223	184	—	0.3	0.2[b,d]
					M = 47,483	98	—	0.27	0.2[b,d]
					F = 30,740	86	—	0.36	0.3[b,d]

AE = athlete exposure; P = prospective; Q = questionnaire; DM = direct monitor; I = interview; M = male; F = female

[a] Any injury for which medical assistance was sought.

[b] Any injury that resulted in withdrawal from competition, inability to practice after the competition, or both.

[c] Per 1,000 hours of participation.

[d] Per 100 participants.

[e] Per 100 participants/yr.

Table 10.2 Percent comparison of injury location in fencing.

	Roi & Fasci (1986)	Majorano & Cesario (1991)	Müller-Strum & Bierner (1991)	Gambaretti et al. (1992)		Naghavi (2000)	Wild et al. (2001)	Kelm et al. (2003)	Jäger (2003)		Harmer (2008a)
				(n = 164)	(n = 49)				(n = 732)	(n = 481)	
Head/spine/trunk	(0.0)	(1.0)	(2.0)	(0.0)	(0.0)	(3.2)	(0.0)	(0.0)	(0.0)	(0.0)	(4.4)
Head/skull	—	—	2.0	—	—	—	—	—	—	—	2.2
Neck/throat	—	1.0	—	—	—	3.2	—	—	—	—	2.2
Trunk/back	—	—	23.0	15.2	12.2	6.5	24.1	9.8	22.6	9.1	9.2
Upper extremity	(63.7)	(67.0)	(20.0)	(6.6)	(20.4)	(77.4)	(9.9)	(26.9)	(21.3)	(7.7)	(19.5)
Shoulder	—	3.0	(inc. in trunk)	3.0	—	—	6.6	4.9	—	7.7	3.8
Arm	9.1	(inc. in shoulder)	8.0	—	—	—	—	4.9	—	—	—
Elbow	—	4.0	—	1.8	4.1	16.1	3.3	—	2.3	—	1.6
Forearm	—	(inc. in elbow)	—	—	—	—	—	9.8	(inc. in elbow)	—	2.7
Wrist	—	60.0	—	—	—	3.2	—	—	19.0	—	11.4
Hand/fingers	54.6	(inc. in wrist)	12.0	1.8	16.3	58.1	—	7.3	(inc. in wrist)	—	(inc. in wrist)
Lower extremity	(27.3)	(23.0)	(55.0)	(68.4)	(53.1)	(12.8)	(66.0)	(63.3)	(42.1)	(77.3)	(63.6)
Pelvis/hips	—	4.0	—	12.2	10.2	—	3.3	—	16.3	8.3	3.8
Thigh	—	2.0	18.0	—	—	3.2	7.9	29.2	(inc. in hip)	(inc. in hip)	15.2
Knee	—	4.0	10.0	9.2	6.1	3.2	20.3	17.1	6.8	34.7	19.6
Leg	9.1	2.0	6.0	—	—	3.2	8.7	2.4	—	8.7	8.7
Ankle	18.2	11.0	21.0	23.2	22.5	3.2	25.8	14.6	29.0	25.6	13.0
Foot/toes	—	(inc. in ankle)	(inc. in ankle)	23.8	14.3	—	—	—	(inc. in ankle)	(inc. in ankle)	3.3
Other	9.1	9.0	—	9.8	14.3	—	—	—	4.0	5.9	3.3

the ankle and knee (Figure 10.1). In addition to prospective studies with this outcome, in the largest retrospective self-report study to date (1,603 respondents), Carter et al. (1993) reported that the knee (17–19%) and ankle (14–14.5%) were cited as the locations of both the worst injury suffered in the previous year and the worst injury suffered in a fencing career.

In the largest prospective, exposure-based study of fencing injury (78,223 participants), Harmer (2008a) noted that while the knee was the most commonly injured region (19.6%), a wide variety of pathologies were involved. Of particular concern were injuries to the anterior cruciate ligament (ACL). Mountcastle et al. (2007) reported that in a 10-year study of sports-related injury at the U.S. Military Academy at West Point, fencing ranked the second lowest of six club sports for which an incidence rate for males was recorded (0.06 per 1,000 AE). No ACL ruptures occurred in females during the study period. Majewski et al. (2006) examined the cause of knee injuries in a 10-year study of patients at an orthopedic clinic in Switzerland and found a rate of 1.5 per 1,000 participants per 10 years for fencing.

Environmental Location

Few studies have examined the distribution of injury between competition and practice. However, Gambaretti et al. (1992), in a 1-year study of 178 fencers (youth through elite level), found that 77% of recorded injuries occurred in practice and 23% in competition. It is not clear from these data, however, whether the rate of injury (i.e., relative to exposure units) would be greater in practice than competition.

When Does Injury Occur?

Injury Onset

To date, only two prospective studies have presented data on injury onset in fencing. From a 1988–1990 study of fencers in the United States, Moyer & Konin (1992) found that 55.2% of the reported injuries were acute and 44.8% were overuse or chronic. Similarly, in a 5-year study of 293 fencers at the German Olympic Training Center in Tauberbischofsheim, Jäger (2003) classified 60.3% of the injuries as acute and 39.7% as overuse. A retrospective study conducted by Carter et al. (1993) in the United States found that of the self-reported cases of "worst injury in the previous year," 67% were acute and 33% overuse or of gradual onset.

Chronometry

No research on the chronometry of injuries in fencing, such as the distribution of injuries over a competitive season or the relative rate of injury during different phases of a fencing tournament, was located.

Figure 10.1 Rapid change of direction and strong lunging place the knee and ankle at risk for injury. Photo by Serge Timacheff. Reprinted with permission.

What Is the Outcome?

Injury Type

The distribution of injury types in fencing derived from the extant literature is detailed in Table 10.3. Three general patterns are evident: (a) studies in which abrasions/blisters and contusions predominate, (b) those in which sprains and strains are most common, and (c) the low proportion of puncture injuries. Taken together, the data indicate that fencing injuries tend to be minor, whether surface trauma (abrasions, contusions) or musculoskeletal derangement (sprains, strains) common to any activity with rapid change of direction activity. For example, in addition to the data in Table 10.3, in an early ecologic study of fencing clubs in England, Weightman & Browne (1975) noted that 28% of reported injuries were sprains and strains, while Moyer & Konin (1992) found that 33% of 323 acute injuries were sprains and 24% were strains in a 2-year study in the United States. The consistently low proportion of puncture wounds underscores the fact that this type of "fencing-specific" injury is not common and studies that reported a high percentage of lacerations (e.g., Naghavi 2000) indicated that these were principally minor cuts to the hand, readily treated with standard wound care such as a bandaid.

Time Loss

In the earliest fencing injury study found in the literature, Nye (1967) classified 32.7% of injuries (17 of 52) as severe (resulted in x-ray examination, medical treatment, or time lost from work; no further breakdown), but indicated that 48% of all injuries required no treatment. In their 1-year study of clubs in northern England, Weightman & Browne (1975) noted that 68% involved no time lost from participation but did not provide any data on time loss for injuries that involved some time loss. Lanese et al. (1990), the only study to date to quantify time loss, reported that eight time-loss injuries in a university fencing team resulted in 21.5 disability days for men (4.3 per 1,000 hours of participation) and 3.5 disability days for women (2.1 per 1,000 hours of participation). Fencing had the lowest rate of time loss of the eight sports studied. Müller-Strum & Bierner (1991) surveyed 105 male and female fencers from Germany and Switzerland and noted that 148 reported injuries resulted in 64 days in the hospital and 203 days missed from work or fencing. Carter et al. (1993) found that 22% of injuries sustained in the previous year did not result in any time loss, but 15% were reported as having an extreme impact on participation. However, no other details were provided. Finally, Naghavi (2000), who reported the highest overall injury rate of any study in this review, emphasized that there were no time-loss injuries and that all injuries were treated with standard first aid.

Clinical Outcome

Catastrophic Injury

Despite the impression of high risk for significant injury from the powerful use of the various weapons in fencing, there have been few fatalities recorded in the literature. Since 1937, only ten deaths worldwide have resulted from penetrating wounds in fencing: all have been in men; 3 in foil, 6 in épée, 1 in saber; 6 occurred in competition, 3 in practice, 1 unknown; 7 resulted from a broken blade, 2 from an intact blade, 1 unknown; 7 penetrations were in the chest, 1 through the neck, 1 in the face, 1 unknown) (Parfitt 1964; Safra 1982; Crawfurd 1984, 1991; "Fencing match" 1990; "Fencer's tragic" 1994; "Ukrainian fencer" 2004; "Fencer dies" 2005; "Smierc szermierza 2009").

Although mortal injuries are very rare, nonfatal penetrating injuries are more frequent but still uncommon. For example, Carter et al. (1993) found that approximately 5% of 1,246 fencers surveyed reported a puncture wound (variously to face, neck, chest, abdomen, arms, and legs) as their worst injury during their fencing career but Harmer (2008a) indicated that only 0.006% of participants in national-level competitions in the United States over a 5-year period suffered a puncture or penetrating wound that resulted in time loss. Wild et al. (2001) noted only one pneumothorax and two lacerations from broken blades in a 15-year study in Germany. Harmer et al. (1996) detailed a distant-entry pneumothorax from a broken épée in an elite fencer, and a pneumohemothorax was reported

Table 10.3 Percent comparison of injury types in fencing.

Study	No. of Injuries	Sprain	Strain	Contusion	Subluxation/ Dislocation	Fracture	Laceration	Puncture	Rupture	Cramp/ Spasm	Abrasion/ Blister	Other/ Unknown
Roi & Fasci (1986)	11	18.2	—	27.3	—	—	9.1	—	—	—	45.5	—
Roi & Facsi (1988)	58	8.6	—	48.3	—	—	—	—	—	6.9	10.3	25.9
Majorano & Cesario (1991)	100	22.0	6.0	18.0	—	1.0	—	—	—	—	46.0	7.0
Müller-Strum & Bierner (1991)	148	24.0	17.0	8.0	Inc. in Other	2.0	—	2.0	6.0	—	—	30.0
Gambaretti et al. (1992)	213	23.0	10.8	—	2.4	5.6	—	—	—	—	—	58.2
Carter et al. (1993)[a]	?	23.9	26.0	—	—	2.1	3.0	3.3	2.4	—	—	39.3
Azémar (1999)	132	26.0	—	44.0	—	—	11.0	—	—	—	10.0	9.0
Naghavi (2000)	31	6.5	3.2	25.8	—	—	38.7	—	—	—	19.3	6.5
Kelm et al. (2003)[b]	41	12.2	12.2	24.4	—	2.4	—	—	46.3	—	—	—
Harmer (2008a)	184	25.5	26.1	12.0	7.6	4.4	0.5	2.7	3.3	4.9	—	13.0

[a] Self-reported worst injury in the previous year.
[b] Self-reported worst injury in previous 5 years.

(also from a broken épée) in a practice session for the 2007 Pan American Games ("Brazilian fencer" 2007). In addition, penetrating injuries have been reported in various locations, including the neck (Harmer 2008c) and abdomen (Matloff 1985). However, the incidence of significant penetrating wounds has not been well researched. In the only study to document the incidence of penetrating wounds resulting in a time loss, Harmer (2008a) noted an overall rate of 0.008 per 1,000 AE (any penetrating injury resulting in time loss) and a rate of 0.0016 per 1,000 AE for penetration wounds to the trunk.

Other Outcomes

In addition to serious injuries, a variety of unique clinical presentations related to fencing have been introduced in the literature. Borelli et al. (1992) described an intravascular papillary endothelial hyperplasia, possibly an organized thrombus, in the hand of a female fencer, postulated to be related to "the continuous microtrauma to which the hand of a fencer is exposed." Gray and Bassett (1990) detailed a case of osteochondritis dissecans in an 18-year-old elite épée fencer, which was surgically repaired without complications. Kelm et al. (2004) presented an instance of acute tibialis anterior rupture in an elite veteran fencer.

Economic Cost

No studies were located that examined the economic impact of fencing injuries on individual athletes, clubs, National Governing Bodies, or the Fédération Internationale d' Escrime (FIE).

What Are the Risk Factors?

Intrinsic Factors

Age

Jäger (2003) argued that poor strength and muscle imbalance in young athletes (≤16 years old) were responsible for injuries in this population, but no data were provided to support this contention. Harmer (2008b), in an analysis involving approximately 42,000 participants, found no significant difference in the rate of time-loss injury (per 1,000 AE) between youth (8–17 years old; 0.27; 95% confidence interval [CI], 0.20–0.35), young adult (~18–30 years old; 0.31; 95% CI, 0.22–0.44), and veteran (≥50 years old; 0.21; 95% CI, 0.10–0.39) fencers.

Sex

In the first study to examine the influence of sex on injuries in fencing, Lanese et al. (1990) found no significant difference in the rate of disability days per 1,000 hours of participation for time-loss injuries between men and women ($P = 0.47$). Similarly, in a 10-year study of cadets at the U.S. Military Academy at West Point, Mountcastle et al. (2007) noted no significant difference in the rate of complete ACL ruptures between men and women (1 case in 16,964 AE vs. 0 in 12,148). However, in their 15-year study of 93 elite German fencers, Wild et al. (2001) concluded that women had a rate of ankle injury that was three times higher than that for men, but no statistical analysis was done. In the largest study of fencing injuries to date, Harmer (2008a) found that women had 35% higher risk for a time-loss injury in competition than men (relative risk, 1.35; 95% CI, 1.01–1.81).

Extrinsic Factors

The only extrinsic risk factor that has been reported is event (i.e., foil, épée, saber). Examining data from the 1991 Italian national competition, Majorano & Cesario (1991) noted that twice as many foil fencers (18.6%) sustained some injury as compared with either épée (8.9%) or saber (9.2%), but the significance of these differences was not tested. Harmer (2008a) found that although foil and épée were not significantly different in the rate of time-loss injuries, saber had a statistically significantly higher risk (62%) for time-loss injury as compared with foil and épée (relative risk, 1.62; 95% CI, 1.2–2.2), and this increased risk was evident for both men (relative risk, 1.61; 95% CI, 1.06–2.44) and women (relative risk, 1.63; 95% CI, 1.05–2.54).

What Are the Inciting Events?

Inciting events have not been extensively examined, but from the available information, three major factors emerge: (a) trauma directly from an opponent's weapon, (b) poor technique (both the opponent's and that of the injured athlete), and (c) injuries from the piste.

An injury resulting from direct impact of the opponents' blade is the most common inciting event: Carter et al. (1993) found 4.5% of self-reported worst injuries in a career were due to the opponent's weapon. Nye (1967) indicated that this mechanism was responsible for 10% of injuries. However, when injury is defined as any request for care, a significantly greater proportion of injuries are attributable to the blade. Roi & Fasci (1986) and Naghavi (2000) reported that 55% to 64.5% of injuries were caused by opponent's weapon (principally minor contusions and abrasions).

Gambaretti et al. (1992) ascribed 63% of ankle injuries to poor foot position, while Carter et al. (1993) cited an athlete's poor technique (12.2–14.7% of injuries) and the opponent's dangerous actions (8.5–9.0%) as important inciting events. Jäger (2003) concluded that both acute and overuse injuries were a result of technical errors, but provided no data to support this claim.

Slipping, tripping, or stepping on the edge of the piste has been identified as responsible for between 9.6% (Carter et al. 1993) and 37% (Gambaretti et al. 1992) of injuries.

Injury Prevention

Although participant safety is presented as a high priority in fencing, no injury prevention studies have been instituted. To date, FIE-mandated changes to equipment and rules related to safety have been based on face validity. For example, the plastron was introduced as a consequence of a fatal penetrating injury in the 1951 World Championships, where it was determined that the fencer's jacket was of inadequate thickness (Parfitt 1964). However, no research has been conducted to determine the actual efficacy of this or any other change.

Similarly, numerous recommendations for decreasing injury have been presented in the literature (Carter et al. 1993; Zemper & Harmer 1996; Roi & Bianchedi 2008) based on descriptive studies, face validity or first principles, covering behavioral characteristics (e.g., improving conditioning and technical expertise), equipment and facilities (e.g., improved composition and construction of the piste, increased integrity of blades and clothing), and administration of fencing competitions (e.g., enforcement of rules on dangerous fencing, enhanced medical coverage). None of these factors has been tested in any prevention intervention.

Further Research

Despite the long history, international scope, and perceived risk of modern competitive fencing, remarkably few well-designed injury studies have been conducted. However, the research that has been completed indicates that, contrary to popular belief, fencing is very safe. The rate of time-loss injuries has been shown to be significantly lower than that for more popular sports such as basketball and soccer, but the majority of fencing injuries are similar to these sports, principally involving sprains and strains in the lower extremities. Although "fencing-specific" injuries, including penetrating wounds, are rare, they remain a major concern.

Given the current dearth of comprehensive epidemiologic data, there are numerous options for future research. However, the first step in this process is to develop broadly implemented surveillance systems, which use a standard definition of a reportable injury, appropriate exposure metric(s), and qualified data recorders, such as medical personnel, and which are directed toward answering a coordinated set of research questions. Principal among these are confirming injury rates for various subpopulations (children, youth, veterans, women, wheelchair) across all three events, and expanding analyses to explore specific risk factors (sex, age, training/experience, etc). Most urgent is the need to explore the antecedents of significant penetrating injuries and fatalities and to institute, and test, meaningful prevention programs to reduce or eliminate rare but catastrophic injuries. With the plethora of local, regional, and international competitions available, an important database could be achieved in a short period and strengthened with the addition of longitudinal data. Information related to the rate and risk factors of practice/training-related injuries will require additional research design efforts to accurately capture rate-based data.

The continuing growth of fencing indicates its enduring appeal as an athletic endeavor and places on researchers and medical personnel the onus to uncover the intricacies of fencing injury to allow participants to enjoy their sport for life.

References

Azémar, G. (1999) La traumatologie spécifique révélée par la compétition en escrime. *Schweizerische Zeitschrift für Sportmedizin und Sporttraumatologie* **47**(2), 79–80.

Borelli, L., Ciniglio, M., Maffulli, N. & Del Torto, M. (1992) Intravascular papillary endothelial hyperplasia in the hand of a fencer. *Pathologica* **84**, 551–556.

Brazilian fencer dropped from Pan Ams after being stabbed in training. (2007) Associated Press, Rio de Janeiro, July 12.

Carter, C., Heil, J. & Zemper, E. (1993) What hurts and why—data from the 1992 USFA Fencing Injury Survey shows some common culprits. *American Fencing* **43**(3), 16–17, 29.

Crawfurd, R. (1984) Death of a fencer. *British Journal of Sports Medicine* **18**(3), 220–222.

Crawfurd, R. (1991) Rapport sur l'accident mortel d'Howard Travis, le 25 Avril 1990, a t'Harde, Pays Bas [in French]. Unpublished report, Amateur Fencing Federation of Great Britain (now British Fencing Association), London.

Fencer dies in Mie Sports Festival. (2005) [in Japanese]. *Yomiuri Shimbun*, October 3, p. 38.

Fencer's tragic death. (1994) *The Irish Times*, January 26, Sport p. 17.

Fencing. (2008) URL http://www.olympic.org [accessed on June 14, 2008]

Fencing match death. (1990) *Financial Times* (London), April 26, Section 1, p. 1.

Gambaretti, R., Berlusconi, M. & Lanzani, A. (1992) La traumatologia da scherma: studio della patologia tipica della disciplina in rapporto all'evoluzione del gesto atletico [in Italian]. *Journal of Sports Traumatology and Related Research* **14**(2), 139–148.

Graham, G. & Bruce, P. (1977) Survey of intercollegiate athletic injuries to women. *Research Quarterly* **48**(1), 21–220.

Gray, W. & Bassett, F. (1990) Osteochondritis dissecans of the patella in a competitive fencer: a case report. *Orthopedic Review* **19**(1), 96–98.

Harmer, P. (2007) Minimal risk of time-loss injury in Masters fencing: USA National and World Championship data 2002–2006. *Medicine & Science in Sports & Exercise* **39**(5), S412 (abstract).

Harmer, P. (2008a) Incidence and characteristics of time-loss injuries in competitive fencing: A prospective, 5-year study of national competitions. *Clinical Journal of Sports Medicine* **18**(2), 137–142.

Harmer, P. (2008b) Rate and characteristics of time-loss injuries do not differ across age groups in competitive fencing. *Medicine & Science in Sports & Exercise* **39**(5), S234 (abstract).

Harmer, P. (2008c) Getting to the point: Injury patterns and medical care in competitive fencing. *Current Sports Medicine Reports* **7**(5), 303–307.

Harmer, P., Moriarity, J., Walsh, M., Bean, M. & Cramer, J. (1996) Distant entry pneumothorax in a competitive fencer. *British Journal of Sports Medicine* **30**, 265–266.

Jäger, A. (2003) Sportverletzungen und schäden beim fechten unter besonderer berücksichtigung des kindes- und jugendalters [in German]. *Sportorthopädie Sporttraumatologie* **19**, 253–261.

Kelm, J., Anagnostakos, K., Deubel, G., Schließing, P. & Schmitt, E. (2004) Ruptur der sehne des musculus tibialis anterior bei einem seniorenfechter der weltklasse [in German]. *Sportverletzung Sportschaden* **18**, 148–152.

Kelm, J., Anagnostakos, K. & Th. Regitz, J. (2003) Verletzungen bei seniorenfechter(inne)n der Weltklasse. *Proceedings of the 3rd Fencing Sports Medicine & Sports Science Symposium*, Germany, pp. 115–117.

Lanese, R., Strauss, R., Leizman, D. & Rotondi, M. (1990) Injury and disability in matched men's and women's intercollegiate sports. *American Journal of Public Health* **80**(12), 1459–1462.

Majewski, M., Habelt, S. & Steinbrück, K. (2006) Epidemiology of athletic knee injuries: a 10-year study. *The Knee* **13**, 184–188.

Majorano, M. & Cesario, S. (1991) Lesioni traumatiche acute nella practica sportiva agnostical della scherma [in Italian]. *Medicina dello Sport* **44**(3), 281–289.

Matloff, M. (1985) Fencing gentlemanly but still dangerous. Reuters, Barcelona, July 18.

Mountcastle, S.B., Posner, M., Kragh, J.F. & Taylor, D.C. (2007) Gender differences in anterior cruciate ligament injury vary with activity: epidemiology of anterior cruciate ligament injuries in a young, athletic population. *American Journal of Sports Medicine* **35**(10), 1635–1642.

Moyer, J. & Konin, J. (1992) An overview of fencing injuries. *American Fencing* **42**(4), 25.

Müller-Strum, A. & Bierner, K. (1991) Fechtsportunfälle—epidemiologie und prävention [in German]. *Deutsche Zeitschrift für Sportmedizin* **42**(2), 49–52.

Naghavi, S.H. (2000) A study of traumatic events in junior fencing competitions. *Escrime* **34**(12), 12–13.

Nye, E. (1967) Fencing injuries—a New Zealand survey. *Australian Journal of Sports Medicine* **2**, 35–39.

Parfitt, R. (1964) The fencer at risk. In: *Injuries in Sport* (Armstrong, J. & Tucker, W., eds.) Staples, London, pp. 173–190.

Raschka, C., Parzeller, M. & Banzer, W. (1999) 15 jährige Versicherungsstatistik zu inzidenzen und unfallhergangstypen von Kampfsportverletzungen im Landessportbund Rheinland-Pfalz [in German] (15 years actuarial statistic concerning insurance related trauma incidences and accident types in the combat sports in the Rhineland-Palatinate sports association). *Sportverletzung Sportschaden* **13**, 17–21.

Roi, G. & Bianchedi, D. (2008) The science of fencing—implications for performance and injury prevention. *Sports Medicine* **38**(6), 465–481.

Roi, G.S. & Fasci, A. (1986) Indagine sugli eventi traumatiei nelle gare giovanili di scherma [in Italian]. *Medicina dello Sport* **39**, 45–48.

Roi, G.S. & Fasci, A. (1988) Indagine sulle richieste di intervento del medico durante le gare di scherma—survey of requests for medical assistance during fencing matches. *Italian Journal of Sports Traumatology* **10**, 55–62.

Safra, J.-M. (1982) La securite en question aprés l'accident de Vladimir Smirnov [in French]. *Escrime* **42**, 26–28.

Smierc szermierza. (2009). [in Polish], URL http://www.zw.com.pl/artykul/538,333093.html [accessed on May 20, 2009].

Ukrainian fencer dies in competition accident. (2004) Deutsche Presse-Agentur, March 15.

Weightman, D. & Browne, R. (1975) Injuries in eleven selected sports. *British Journal of Sports Medicine* **9**(3), 136–141.

Wild, A., Jaeger, M., Poehl C., Werner, A., Raab, P. & Krauspe, R. (2001) Morbidity profile of high-performance fencers. *Sportverletzung Sportschaden* **15**, 59–61.

Zemper, E. & Harmer, P. (1996) Fencing. In: *Epidemiology of Sports Injuries* (Caine, D., Caine, C. & Lindner, K., eds.) Human Kinetics, Champaign, IL, pp. 186–195.

Chapter 11

Field Hockey

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Introduction

Field hockey continues to be one of the most popular team sports played by men and women throughout the world. According to the International Hockey Federation (FIH), it currently consists of five continental federations and a total of 122 member associations (FIH 2006). Since the 1976 Olympics in Montreal, Quebec, Canada, when the first Olympic competition was held on artificial turf, all international matches have been played on this surface.

The purpose of this chapter is to review the research on injury in field hockey and to use this information to suggest methods for injury prevention and to guide future investigations.

Who Is Affected by Injury?

Injury is common in field hockey, and up to 75% of field hockey players have sustained at least one acute injury during a game or practice (Murtaugh 2001). Table 11.1 summarizes the published rates of acute injury by gender and level of competition. Most studies suggest that injury rates in hockey are comparable to, or lower than, the rates in other team sports, such as basketball, soccer, and lacrosse. For example, Nicholl et al. (1995) evaluated injury in recreational sport and found a rate of 62.6 injuries per 1,000 occasions of participation for hockey, compared to 64.4 injuries per 1,000 occasions for soccer. In the National Collegiate Athletic Association (NCAA) in the United States, during 2004–2005, the overall game injury rate for women was 11.4 injuries per 1,000 athlete exposures (AEs) for field hockey and 15.7 injuries per 1,000 AEs for lacrosse (NCAA 2008). At the high-school level, Powell & Barber-Foss (1999) documented 3.7 field hockey injuries per 1,000 AEs versus 5.3 soccer injuries per 1,000 AEs. During the 2004 Olympic Games in Athens, Greece, field hockey injuries (men, 55 injuries per 1,000 game exposures; women, 17 per 1,000) occurred at a lower rate than in basketball (men, 64 per 1,000; women, 67 per 1,000) or soccer (men, 109 per 1,000; women, 105 per 1,000) (Junge et al. 2006). However, Backx et al. (1989) found that field hockey had the highest rate of injury for girls (risk ratio, 2.6) but the second highest rate for boys (risk ratio, 1.3) when comparing the observed to the expected rate of injury across 14 school sports. The relative injury rate was determined by comparing the injury rate for each of 14 sports to the rate for the total study population (106 injuries per 1,000 participants). In Ireland, hockey was second only to rugby in the number of injuries to children that presented to the emergency room (ER) (Abernethy & MacAuley 2003).

Unfortunately it is difficult to compare values between studies since different methods have been used and players of different levels or age groups are rarely included in the same sample. A key factor that influences the injury rate in any research study is the injury definition. For instance, some

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Table 11.1 Injury rates in men's and women's field hockey.

Study	Population	No. in Sample	Injury Definition	Study Design	Rate of Injury
WOMEN					
Powell & Barber-Foss (1999)	High school	442	Medical attention and restricted participation	P	3.7/1,000 AEs
Murtaugh (2001)	High school, college, and elite	158	Self-reported	R	0.4/athlete-year
Fuller (1990)	Recreational (100.2 hours of match play)	NA	Medical attention	P	1,340/1,000 hr match play
Dick et al. (2007)	College	NA	Medical attention and restricted participation	P	7.9/1,000 AEs (game)
Graham & Bruce (1977)	College	275	Debilitating to performance[a]	P	0.3/player/season
Lindgren & Maguire (1985)	Elite	10	NA	P	6/player/year
Freke & Dalgleish (1994a)	Elite	40	Medical attention	R	2.4/player/career
Freke & Dalgleish (1994c)	Elite	62	Medical attention	P	1.9/player/4 tournaments
Westbrook (2000)	Elite	24	Medical attention	P	34.0/1,000 player-hours
Junge et al. (2006)	Elite (29 matches)	NA	Medical attention	P	17/1,000 player-matches
MEN					
Lindgren & Maguire (1985)	Elite	16	NA	P	3.1/player/yr
Junge et al. (2006)	Elite (42 matches)	NA	Medical attention	P	55/1,000 player-matches
BOTH					
Nicholl et al. (1995)	Recreational	NA	Self-reported	R	62.6/1,000 AEs
Roberts et al. (1995)	Recreational	50	Self-reported	R	1.4/player/yr
		50	Self-reported	P	2.4/player/season
Jung et al. (1998)	Recreational	130	Self-reported	R	1.7/player/year
Finch et al. (2002)	Recreational	393	Self-reported[b]	P	15.2/1,000 hr

AE = athlete exposure; NA = not available; P = prospective; R = retrospective.
[a] The player's coach or athletic trainer completed the forms stating whether the injury was debilitating to the athlete's performance.
[b] The injury definition of Finch et al. (2002) included that the injury must have required medical attention or restricted participation, whereas the other studies included any self-reported injury.

studies asked athletes to report any injuries without specifying severity or time loss (Fuller 1990; Nicholl et al. 1995; Roberts et al. 1995; Jung et al. 1998; Murtaugh 2001), while others used any medical attention as the threshold for detecting an injury (Freke & Dalgleish 1994a, 1994c; Junge et al. 2006). A more strict injury definition involves both the diagnosis of the injury by a certified medical professional, such as an athletic trainer, and some component of time loss from activity (Powell & Barber-Foss 1999; Dick et al. 2007). A review of the injury rates reported Table 11.1 reveals that studies with a broader injury definition tend to report higher rates because more minor injuries are detected. The main advantage of a more rigorous injury definition is that it allows researchers to replicate methods between studies, thereby enabling more-valid comparisons between these studies.

Table 11.2 Site of injury as a percent of the total injuries in men's and women's field hockey.[a]

Study	Population	No. in Sample	Head/ Face	Upper Limb	Back/ Torso	Lower Limb	Other/Not Reported
WOMEN							
Powell & Barber-Foss (1999)	High school	442	16.6	15.8	4.9	**58.8**	3.3
Murtaugh (2001)	High school, college, and elite	158	34.0	14.0	1.0	**51.0**	0.0
Fuller (1990)	Recreational	NA	10.4	20.0	8.9	**60.7**	0.0
Rose (1981)	College	NA	11.1	4.9	4.9	**79.0**	0.0
Dick et al. (2007)							
Game	College	NA	25.3	20.7	7.1	**43.2**	3.8
Practice	College	NA	8.4	8.1	16.2	**60.2**	7.1
Lindgren & Maguire (1985)	Elite	10	1.7	5.0	16.7	**76.7**	0.0
Freke & Dalgleish (1994a)	Elite	40	0.0	11.6	21.1	**65.3**	2.1
Freke & Dalgleish (1994c)	Elite	62	4.3	13.0	23.2	**59.4**	0.0
Westbrook (2000)	Elite	24	7.3	10.1	21.1	**61.5**	0.0
Junge et al. (2006)	Elite	NA	27.0	20.0	9.0	**47.0**	0.0
MEN							
Lindgren & Maguire (1985)	Elite	16	6.1	8.2	12.2	**69.4**	4.1
Junge et al. (2006)	Elite	NA	22.0	20.0	8.0	**50.0**	0.0
BOTH							
Eggers-Ströder & Hermann (1994)	Recreational	322		19.0		**62.0**	19.0[b]
Yard & Comstock (2006)	ER presentations (2–18 y)	1356	28.0	**39.4**	0.0	28.2	4.4
Sherker & Cassell (1998)	ER presentations—all ages	292	**32.8**	31.7	NA	12.7	22.8

ER = emergency room; NA = not available.
[a] The highest value for each study is in **bold** type.
[b] Eggers-Ströder & Hermann (1994) combine head and trunk injuries.

Where Does Injury Occur?

Anatomical Location

The majority of researchers have found that the lower limb is the most frequently injured site of the body (Table 11.2). A more detailed breakdown of the site of lower-limb injuries is presented in Table 11.3.

There is also a significant risk of damage to the head and face in field hockey. Graham and Bruce (1977) found that field hockey had the highest rate of head and face injuries of the nine sports they studied. Many athletes (42–62%) have had at least one facial injury (Bolhuis 1987; Murtaugh 2001). Field hockey also had the second highest incidence of dental injury for women and accounted for 1.3% of the total dental injuries at the 1989 Canada Games (Lee-Knight et al. 1992).

The next most common site of injury is the upper limb. It is difficult to determine whether field hockey has a higher rate of upper-limb injury than other sports because there is limited information on the overall rate of upper-limb injury in athletes. However, a review by Rettig (1998) suggests that hand and wrist injuries comprise 3% to 9% of all sports injuries and that most incidents are associated with competition. Most of the hockey studies cited in Table 11.2 indicate a higher range than Rettig's (1998) values (4.9–39.4%).

Environmental Location

Although 60% to 70% of all women's hockey injuries occur during practice (a finding that is consistent for all levels of hockey; Powell & Barber-Foss 1999; Westbrook 2000; Dick et al. 2007), the rate of injury

Table 11.3 Site of lower limb injury as a percent of the total injuries in men's and women's field hockey.[a]

Study	Population	No. in Sample	Hip/Thigh	Knee	Leg	Ankle/Foot
WOMEN						
Powell & Barber-Foss (1999)	High school	442	21.8[b]	13.7	NA	**23.3**
Fuller (1990)	Recreational	NA	17.0	**24.4**	5.2	14.1
Rose (1981)	College	NA	13.6	11.1	8.6	**40.8**
Dick et al. (2007)						
Game	College	NA	9.9	17.6	2.9	**18.1**
Practice			**26.9**	17.3	7.9	16.7
Lindgren & Maguire (1985)	Elite	10	11.7	11.7	6.7	**18.3**
Freke & Dalgleish (1994a)	Elite	40	15.0	16.0	8.0	**26.0**
Freke & Dalgleish (1994c)	Elite	62	**17.0**	13.0	13.0	**17.0**
Westbrook (2000)	Elite	24	**22.9**	14.7	6.4	16.5
Junge et al. (2006)	Elite	NA	0.0	0.0	0.0	**13.0**
MEN						
Lindgren & Maguire (1985)	Elite	16	**22.4**	**22.4**	8.2	10.2
Junge et al. (2006)	Elite	NA	0.0	**22.0**	3.0	17.0

NA = not available.
[a] The highest value for each study is in **bold** type.
[b] Powell & Barber-Foss (1999) combine hip, thigh, and leg injuries.

is much higher during matches. The relative risk of 1.5 to 2.1 of sustaining injury during a game as compared with during practice (4.9 vs. 3.2 per 1,000 AEs for high school [Powell & Barber-Foss 1999]; 7.9 vs. 3.7 for college [Dick et al. 2007]; 22.0 vs. 10.0 for elite players [Westbrook 2000]). Furthermore, Dick et al. (2007) found that players were more likely to sustain severe injuries, such as concussions, facial injuries, and knee internal derangements during games. Unfortunately, there are no data that compare practice and game injury rates in men's hockey.

When Does Injury Occur?

Injury Onset

The prevalence of chronic injury in field hockey ranges from 12% to 55% of total injuries (Fuller 1990; Freke & Dalgleish 1994a, 1994c; Westbrook 2000) and may be more common in elite athletes (Lindgren & Maguire 1985; Sherker & Cassell 1998; Westbrook 2000).

The majority of these chronic injuries affect the lower back and lower limb. Chronic back pain, or treatment for previous lumbar spinal conditions has been found in 45% to 78% of field hockey players (Lindgren & Twomey 1988; Freke & Dalgleish 1994a, 1994b; Jung et al. 1998). Reinking (2006) followed a group of female collegiate players over one season and reported that 89% had exercise related-leg pain. The most common chronic knee injuries have been reported as patellofemoral pain, patellar tendinitis, and iliotibial band friction syndrome (Devan et al. 2004). Most shin pain has been related to exertional compartment syndrome or medial tibial stress syndrome (Reinking 2006). Freke & Dalgleish (1994a, 1994c) found that 7% of their athletes were diagnosed with medial tibial stress syndrome.

Chronometry

Few studies have reported on what time of the game or season injury occurs. Westbrook (2000) found that 58% of acute injuries occurred during the second half of games. However, Junge et al. (2006) reported the same rate of injury during both halves of the matches at the 2004 Olympics. It is also unclear whether the time of the season influences injury rates. Finch et al. (2002) studied community-level hockey, and the highest rate of injury occurred during the first 4 weeks of the first season studied (24.4 injuries per 1,000 exposure-hours). However, this result was not replicated in the second playing season (11.7 injuries per 1,000 exposure-hours), when the highest rate of injury was during the fourth month of competition (21.0 injuries per 1,000 exposure-hours). Finch et al. (2002) suggest that newly recruited subjects may have reported more injuries in the first month of the study, creating a reporting bias during the first season of the study. At the college level, the practice-injury rate has been found to be highest in the preseason (6.4 injuries per 1,000 AEs) as compared with in-season (2.21 injuries per 1,000 AEs) or postseason practice (1.63 injuries per 1,000 AEs). In contrast, game injuries have been found to be highest in-season (8.0 injuries per 1,000 AEs) versus preseason (6.5 injuries per 1,000 AEs) or postseason (7.2 injuries per 1,000 AEs) (Dick et al. 2007).

What Is the Outcome?

Injury Type

The majority of field hockey injuries are minor sprains and strains (Table 11.4) followed by contusions and wounds or lacerations. The wide range of values in each category in Table 11.4 reflects the methodologic differences between studies, including different injury definitions.

Finch et al. (2002) found that hockey had the highest proportion of community-level athletes who sustained a contusion (79.5%) or laceration (15.2%). Many of these injuries required medical attention. For example, the most common hockey-related ER diagnosis in Australia is an open wound (20.5% of injuries) (Sherker & Cassell 1998). In the United States, contusions and abrasions accounted for 79.5% of hockey-related ER visits by children (Yard & Comstock 2006).

As indicated in Table 11.3, most injuries affect the lower limb, and the most common specific injury is an ankle sprain (Graham & Bruce 1977; Rose 1981; Dick et al. 2007). Beynnon et al. (2005) studied a cohort of female high-school and college field hockey players (n = 138) and reported a first-time ankle-injury rate of 0.9 (95% confidence interval [CI], 0.4–1.9) injuries per 1,000 person-days, which was lower than for basketball players but not significantly different from soccer or lacrosse.

Time Loss

Most hockey injuries do not limit participation. For example, when nine sports were studied in schoolchildren, field hockey had the lowest proportion of injuries that caused over a week of nonparticipation (Powell & Barber-Foss 1999), with 79.6% of injuries resulting in <8 days away from participation, 13.6% of injuries requiring 8 to 21 days off, and 7.1% needing >21 days away. Dick et al. (2007) reported that 15% of game injuries and 13% of practice injuries in the NCAA restricted participation for ≥ 10 days. The rate for injuries causing >7 days of time loss was 3.0 per 1,000 AEs during the 2004–2005 season (NCAA 2008). The study by Junge et al. (2006) is the only one that attempted to evaluate overall time loss among elite athletes. Although there was no follow-up after the 2004 Olympic Games, team physicians estimated the duration of each injured player's absence from training or matches. It was reported that 45% of injured athletes expected to miss matches or training and 89% of these time-loss injuries were expected to cause an absence of up to 1 week. On average, a time-loss injury occurred every third match and the incidence of time-loss injuries was 16 (95% CI, 9–23) per 1,000 player-matches.

There is limited information on which injuries affect participation the most. Up to 12% of female field hockey players have been found to miss a game or take time off from school or work because of back pain (Murtaugh 2000). However, Rose (1981) found that second-degree ankle sprains caused the most disability (as determined by the team physician). In elite players, over half of the dental injuries sustained have been found to require a visit to a physician, a dentist, or both (Elliott & Jones 1984; Bolhuis 1987; Sherker & Cassell 1998; Yard & Comstock 2006).

Clinical Outcome

Powell & Barber-Foss (1999) reported that only 1.2% of field hockey injuries require surgery. However, Roberts et al. (1995) revealed that recreational athletes are playing and training at less than full capacity during 10.7% of the season. Recurrent injury also contributes significantly to ongoing disability. In schoolchildren, 10.5% of the acute injuries have

Table 11.4 Types of acute injury as a percentage of the total injuries in men's and women's field hockey.[a]

Study	Population	No. in Sample	Sprain	Strain	Contusion	Fracture	Wound/ Laceration	Concussion	Other/Not Reported
WOMEN									
Powell & Barber-Foss (1999)	High school	442	**25.5**	20.2	—	5.9	—	—	48.4
Murtaugh (2001)	High school, college, and elite	158	**39.7**	8.1	17.1	16.4	9.4	7.7	1.6
Rose (1981)	College	NA	**32.1**	18.5	**32.1**	1.2	6.2	3.7	6.2
Dick et al. (2007)			**23.9**	16.9	19.8	15.4	11.2	9.4	3.4
Game	College	NA							
Practice			22.8	**57.9**	—	4.5	—	3.4	11.4
Lindgren & Maguire (1985)	Elite	10	19.5	**24.4**	22.0	2.4	2.4	—	29.3
Freke & Dalgleish (1994a)	Elite	40	24.0	**32.0**	3.0	11.0	—	—	30.0
Freke & Dalgleish (1994c)	Elite	62	8.0	**32.0**	23.0	3.0	9.0	—	25.0
Westbrook (2000)	Elite	24	7.3	**13.8**	10.1	2.7	1.8	0.9	63.4
Junge et al. (2006)	Elite	NA	13.0	—	**37.0**	—	25.0	25.0	—
MEN									
Lindgren & Maguire (1985)	Elite	16	**25.0**	17.5	17.5	2.5	7.5	—	30.0
Junge et al. (2006)	Elite	NA	19.0	8.0	**42.0**	8.0	19.0	—	4.0
BOTH									
Roberts et al. (1995)	Recreational	50	23.7	15.3	**26.3**	—	—	—	34.7
Sherker & Cassell (1998)	ER presentations—all ages	292	14.7		—	16.4	**32.5**	—	36.4

ER = emergency room; NA = not available.
[a] The highest value for each study is in **bold** type (excluding "Other/Not Reported" injuries).

been found to be reinjuries, and this proportion rises to 27% in recreational players and 44% in elite athletes (Graham & Bruce 1977; Fuller 1990; Powell & Barber-Foss 1999).

Catastrophic Injury

There have been no reported fatalities in hockey. However, field hockey was shown to have the fourth highest incidence of eye injuries among the 16 sports followed by the NCAA Injury Surveillance System from 2000 to 2004 (Cyr 2006), with 11% of head and facial injuries also affecting the eye (Elliott & Jones 1984). The National Center for Catastrophic Sport Injury Research (2007) has studied serious injury in U.S. scholastic and collegiate sport since 1982 and has documented two eye injuries and three head injuries (two skull fractures) due to the impact of a hockey ball. Concussions account for 1.7% to 7.7% of acute injuries (Murtaugh 2001; Finch et al. 2002; Covassin et al. 2003; Dick et al. 2007). Head injuries have been shown to account for 5.1% of ER presentations in hockey, with a 10.5% admission rate, while intracranial injuries (e.g., concussion, subdural hematoma) had a 25.0% admission rate (Sherker & Cassell 1998).

Economic Cost

There are no data available on the economic cost of field hockey injuries.

What Are the Risk Factors?

Intrinsic Factors

Multiple anatomical, physiologic, and psychological factors may influence injury in hockey players. For example, Murtaugh (2001) reported that injured players (n = 40) were significantly younger (mean ± SD, 18.0 ± 2.6 vs. 20.4 ± 3.2 years) and had less experience (5.4 ± 3.5 vs. 7.4 ± 3.3 years) than uninjured players (n = 118) in a study of female players.

Sex has also been found to affect the rate and type of injury in hockey. In particular, male players appear to sustain injury more often and to suffer more severe injuries than female players (Lindgren & Maguire 1985; Finch et al. 2002). For example, in Australia, more men are registered as field hockey players, with a ratio of 1.3 male player to every female player. However, men presented to the Victorian hospital ER (1996–1997) 1.7 times more than women for hockey injuries (n = 292 field hockey-related presentations) (Sherker & Cassell 1998). The injury rates reported at the 2004 Olympic Games suggest that elite men have 3.2 times greater risk than elite women of sustaining any injury in a game and are six times more likely to sustain a time-loss injury in a match (odds ratio, 6.0; 24 injuries per 1,000 player-matches [95% CI, 12–36] vs. 4 [95% CI, 0–10]). Overall, 75% of women versus only 52% of men were able to continue participating, without interruption, after an injury (Junge et al. 2006).

Extrinsic Factors

The playing surface, equipment, rules and other athletes may influence the pattern of injuries in hockey, although only limited research as been conducted. Spedding (1986) surveyed players and coaches in Australia. They thought that the game had become safer due to improvements in umpiring interpretations and the introduction of artificial turf. Since that time, there have been additional rule changes, including the elimination of the offside rule, and now most matches are played on artificial turf. Dick et al. (2007) compared injury patterns in the NCAA before and after 1996, when many of these changes occurred and found a statistically significant decrease in game injury rates between the early years (8.7; 95% CI, 8.03–9.28 injuries per 1,000 AEs for 1988–1989 to 1995–1996) and the later years (6.9; 95% CI, 6.29–7.53 for 1996–1997 to 2002–2003). The decrease was due to declines in ankle, knee, and finger injuries. However, the rate of head injuries (concussions and lacerations) increased. It is unclear which factor(s) may be responsible for the changes.

In terms of field position, Murtaugh (2001) reported that goalkeepers had the highest rate of injury (0.6 per athlete-year vs. 0.5 for midfield players and 0.4 for forwards and defense players) and 16.7 times more back and torso injuries than field players. Midfielders had the highest rate of injuries to the head and face and upper limb, and defenders had a higher rate of lower limb injury (0.3 vs. 0.2 injuries per athlete-year). Dick et al. (2007) found a similar trend. Unfortunately, neither Dick et al. (2007) nor Murtaugh (2001) evaluated these data for statistical significance.

What Are the Inciting Events?

The situations that lead to the most injuries in hockey are tackling and set plays. Tackling, which accounts for 17% to 20% of injuries, is an attempt to gain possession of the ball. Players may come in contact with the turf, the stick, the ball, or each other (Figure 11.1) (Graham & Bruce 1977; Hume et al. 2003). The most common set plays are free hits and short corners. Intention is often disguised during the shot, and the closest players must stop or avoid a fast-moving ball. Most of these high-risk activities in hockey occur inside the 25-yard line and, consequently, two thirds of game injuries occur in this area. This rate includes the 26% of injuries that occur around the goal (Dick et al. 2007).

Figure 11.1 A player is engaged in an attempted tackle, during which he risks contact with the turf, the ball, the stick, or the other player. Photo courtesy of Hockey Australia. Reprinted with permission.

Disregarding the rules may also increase injury. Team physicians at the 2004 Olympic Games concluded that 19% of recorded injuries were caused by foul play (Junge et al. 2006).

Injury Prevention

Using protective equipment is the most obvious method of reducing injury in sport. It is widely accepted that shin guards reduce injuries to the lower leg in soccer; however, to the author's knowledge, no data on the benefits of shin guards in field hockey have been published. Similarly, there are no known data on how the development of light and resilient foams in goalkeeping equipment has affected injury patterns for goalkeepers or the surrounding field players.

Further Research

Most of the available research on hockey injuries focuses on describing their nature and rate. Unfortunately, it is difficult to compare studies because they use different injury definitions and varied study designs. In addition, many authors focus only on elite athletes eventhough a review of Australian ER data found that players 11 to 19 years of age accounted for 50% of the hockey injuries (Sherker & Cassell 1998). The sport would benefit from an in-depth study of injury patterns at all levels.

The research team should involve coaches and athletic trainers, physicians to confirm each diagnosis, and epidemiologists to develop the study design and analyze the data. The best injury definition would incorporate a time-loss component (e.g., no participation on the day of the injury and the following day), which would minimize the inclusion of minor injuries that do not have serious consequences. The FIH has a medical section that produces forms for match-injury and medical-incident reporting. This association, along with local hockey associations, is ideally positioned to help provide the infrastructure needed for injury surveillance.

The largest gap in hockey injury information involves how injuries occurs and the effectiveness of preventive strategies. Although the literature indicates that adhering to and enforcing the rules of the game, a commitment to physical preparation, and the use of appropriate protective equipment will reduce injuries (Fox 1981; Rose 1981; Spedding 1986; Moore 1987; Sherker & Cassell 1998), there is little research to support these suggestions. Therefore, the focus of new research should be on identifying the situations that lead to injury and the specific mechanisms of injury. For example, Lindgren & Maguire (1985) argued that unaccustomed high-intensity training on artificial turf was the major contributing factor to the high incidence of overuse injuries in their women's squad, and Reinking (2006) suggested that differences in the incidence of exercise-related leg pain between teams he studied were related to the training surface. However, no one has investigated these claims. Similarly, although deliberate physical contact is not permitted in field hockey, incidental contact seems to be contributing to a larger proportion of injuries in more recent studies. Twenty years ago, contact was responsible for only 2.2% of injuries, but in a 2007 review of NCAA players, it caused 13% of injuries (Fuller 1990; Dick et al. 2007). It is unclear whether this discrepancy is due to changes in the game or differences in the study populations. Fox (1981) suggested that experience, position, and psychological factors were the most important injury risk factors. Kolt and Roberts (1998) collected injury data and a self-esteem inventory over a 20-week season from 50 players. Multiple-regression analysis indicated that the frequency of more severe injuries significantly predicted self-esteem scores ($P = 0.01$) and Rose (1981) identified an inverse relationship between success and injury. Further work is needed to understand the importance of these characteristics and how they may be manipulated to decrease injury rates.

As risk factors are identified and confirmed, they should be evaluated statistically for their association with specific injuries and their predictive value. This information can be used to develop evidence-based guidelines for prevention. Data should also be collected prospectively as new rules and new equipment are introduced into the game to evaluate the effects of these changes. Other related issues include, whether children or inexperienced players are at greater risk, whether current protective equipment is effective, and whether specific training programs can prevent injury. For example, it has been demonstrated in other settings that balance training and ankle bracing reduce the rate of recurrent ankle sprains and may reduce first time injuries (Verhagen et al. 2000).

Given that over 78% of head and face injuries are from stick or ball contact (Jung et al. 1998; Murtaugh 2001; Dick et al. 2007) and, in Australia, two thirds of hockey-related ER visits are due to injuries caused by the stick (Sherker & Cassell 1998), the almost universal absence of facial protection needs to be examined (Elliott & Jones 1984). Several authors have advised hockey associations to require eye or face protection or both (Jones 1989; Cyr 2006; Yard & Comstock 2006). Recently, the FIH rules were modified to allow the use of a face or head protector if there are documented medical concerns (FIH 2006). The NCAA has extended this option to all field players. These changes acknowledge the issue of facial and head injury, but there is no known research on the appropriate design or effectiveness of the proposed devices. It should be the priority of the hockey administrators to ensure that this equipment is safe. In addition, hockey associations and governing bodies should drive the development of policies that incorporate evidence-based guidelines into the initial management of head and brain injury, and return-to-play decisions following head and brain injury (McManus 2006).

Finally, a meta-analysis has indicated that the overall risk of an orofacial injury is 1.6 to 1.9 times higher if a mouth guard is not worn during sports with a risk of facial injury (Knapik et al. 2007). Consequently, the American Dental Association and the International Academy of Sports Dentistry recommend mouth-guard use for hockey

(American Dental Association 2004). A survey of 359 American parents cited field hockey, along with football, boxing, ice hockey, wrestling, and karate as sports in which mouth-guard use ought to be mandatory (Diab & Mourino 1997). However, studies suggest that players do not wear mouth guards consistently because of discomfort or interference with breathing (Bolhuis et al. 1987). It is clear that studies to determine the effectiveness of mouth-guard use in hockey are required.

References

Abernethy, L. & MacAuley, D. (2003) Impact of school sports injury (Short Report). *British Journal of Sports Medicine* **37(4)**, 354–355.

American Dental Association. (2004) The importance of using mouthguards: tips for keeping your smile safe. *Journal of the American Dental Association* **135**, 1061.

Backx, F.J.G., Erich, W.B.M., Kemper, A.B.A. & Verbeek, A.L.M. (1989) Sports injuries in school-aged children: an epidemiologic study. *American Journal of Sports Medicine* **17(2)**, 234–240.

Beynnon, B.D., Vacek, P.M., Murphy, D., Alosa, D. & Paller, D. (2005) First-time inversion ankle ligament trauma: the effects of sex, level of competition, and sport on the incidence of injury. *American Journal of Sports Medicine* **33(10)**, 1485–1491.

Bolhuis, J.H.A., Leurs, J.M.M. & Flögel, G.E. (1987) Dental and facial injuries in international field hockey. *British Journal of Sports Medicine* **21**(4), 174–177.

Covassin, T., Swanik, C.B. & Sachs, M.L. (2003) Epidemiological considerations of concussions among intercollegiate athletes. *Applied Neuropsychology* **10**(1), 12–22.

Cyr, K. (2006) Focus needed on field hockey eyewear. 2006. *NCAA News*, **43**(12), 4.

Devan, M.R., Pescatello, L.S., Faghri, P. & Anderson, J. (2004) A prospective study of overuse knee injuries among female athletes with muscle imbalances and structural abnormalities. *Journal of Athletic Training* **39**(3), 263–267.

Diab, N. & Mourino, A.P. (1997) Parental attitudes toward mouthguards. *Pediatric Dentistry* **19**(8), 455–460.

Dick, R., Hootman, J.M., Agel, J., Vela, L., Marshall, S.W. & Messina, R. (2007) Descriptive epidemiology of collegiate women's field hockey injuries: National Collegiate Athletic Association injury surveillance system, 1988–1989 through 2002–2003. *Journal of Athletic Training* **42**(2), 211–220.

Eggers-Ströder, G. & Hermann, B. (1994) [Injuries in field hockey] [German]. *Sportverletz Sportschaden* **8**(2), 93–97.

Elliott, A.J. & Jones, D. (1984) Major ocular trauma: a disturbing trend in field hockey injuries. *British Medical Journal* **289**, 21–22.

FIH Organisational Chart. 2006. URL http://www.worldhockey.org/vsite/vfile/page/fileurl/0,11040,1181-168652-185870-94006-0-file,00.pdf.[accessed on October 31, 2007]

Finch, C., Da Costa, A., Stevenson, M., Hamer, P. & Elliott, B. (2002) Sports injury experiences from the Western Australian sports injury cohort study. *Australian and New Zealand Journal of Public Health* **26**(5), 462–467.

Fong, D.T.P., Hong, Y., Chan, L.K., Yung, P.S.H. & Chan, K.M. (2007) A systematic review on ankle injury and ankle sprain in sports. *Sports Medicine* **37**(1), 73–94.

Fox, N. (1981) Risks in field hockey. In: *Sports Fitness and Sports Injuries* (Reilly, T, ed.), Faber & Faber, Boston, pp. 112–117.

Freke, M. & Dalgleish, M. (1994a) Injuries in women's field hockey: Part One. *Sport Health* **12**(1), 41–42.

Freke, M. & Dalgleish, M. (1994b) Incidence of low back dysfunction in young elite female field hockey players. *Sport Health* **12(2)**, 32–33.

Freke, M. & Dalgleish, M. (1994c) Injuries in women's field hockey: part two—on tour. *Sport Health* **12(3)**, 44–46.

Fuller, M.I. (1990) A study of injuries in women's field hockey as played on synthetic turf pitches. *Physiotherapy in Sport* **12**(5), 3–6.

Graham, G.P. & Bruce, P.J. (1977) Survey of intercollegiate athletic injuries to women. *The Research Quarterly* **48**(1), 217–220.

Hume, P., Cheung, K., Brooks, D. & Gianotti, S. (2003) Soccer, hockey and touch injuries in New Zealand tournaments 1999–2002. *Journal of Science and Medicine in Sport* **6**(Suppl), 60.

International Hockey Federation (FIH). (2006) *Rules of Hockey, including explanations. Effective from 1 January 2007 for the years 2007 and 2008*. The International Hockey Federation, Lausanne, Switzerland.

Jones, N.P. (1989) Eye injury in sport. *Sports Medicine* **7**(3), 163–181.

Jung, R., Dufek, P. & Traut, R. (1998) Feld—und Hallenhockey: Belastung und Gefaerhdung des Bewegungsapparates durch Verletzungen und Sportschaeden [German]. *Deutsche Zeitschrift fuer Sportmedizin* **49**(11/12), 332–339.

Junge, A., Langevoort, G., Pipe, A., Peytavin, A., Wong, F., Mountjoy, M., Beltrami, G., Terrell, R., Holzgraefe, M., Charles, R. & Dvorak, J. (2006) Injuries in team sport tournaments during the 2004 Olympic Games. *The American Journal of Sports Medicine* **34**(4), 565–575.

Knapik, J.J., Marshall, S.W., Lee, R.B., Darakjy, S.S., Jones, S.B., Mitchener, T.A., delaCruz, G.C. & Jones, B.H. (2007) Mouthguards in sport activities: History, physical properties and injury prevention effectiveness. *Sports Medicine* **37**(2), 117–144.

Kolt, G.S. & Roberts, P.D.T. (1998) Self-esteem and injury in competitive field hockey players. *Perceptual and Motor Skills* **87**, 353–354.

Lee-Knight, C.T., Harrison, E.L. & Price, C.J. (1992) Dental injuries at the 1989 Canada games: an epidemiological study. *Journal of the Canadian Dental Association*. **58**(10), 810–815.

Lindgren, S. & Maguire, K. (1985) Survey of field hockey injuries. *Sports Science and Medicine Quarterly* **1**(3), 7–12.

Lindgren, S. & Twomey, L. (1988) Spinal mobility and trunk muscle strength in elite hockey players. *Australian Journal of Physiotherapy* **34**(3), 123–130.

McManus, A. (2006) Management of brain injury in non-elite field hockey and Australian football—a qualitative study. *Health Promotion Journal of Australia* **17**(1), 67–69.

Moore, S. (1987) Field hockey. In: *Catastrophic Injuries in Sports: Avoidance Strategies*, 2nd ed. (Adams, S.H., Adrian, M.J. & Bayless, M.A., eds.), Benchmark Press Inc., Indianapolis, IN, pp. 67–74.

Murtaugh, K. (2000) EMG analysis of the field hockey drive. *Proceedings* *of Combined Meeting of SB and CSB, 23–26 August, 2000*, Montreal, Quebec, Canada, p. 128.

Murtaugh, K. (2001) Injury patterns among female field hockey players. *Medicine and Science in Sports and Exercise* **33**(2), 201–207.

National Center for Catastrophic Sport Injury Research. (2007) 24th Annual Report. Fall 1982–Spring 2006. URL http://www.unc.edu/depts/nccsi/AllSport.htm [accessed on October 31, 2007]

NCAA. (2008). Injury Surveillance System (ISS) Data 2004-2005. URL http://www.ncaa.org/wps/ncaa?ContentID=1162 [accessed on June 4, 2008]

Nicholl, J.P., Coleman, P. & Williams, B.T. (1995) The epidemiology of sports and exercise related injury in the United Kingdom. *British Journal of Sports Medicine* **29**(4), 232–238.

Powell, J.W. & Barber-Foss, K.D. (1999) Injury patterns in selected high school sports: a review of the 1995–1997 seasons. *Journal of Athletic Training* **34**(3), 277–284.

Reinking, M.F. (2006) Exercise-related leg pain in female collegiate athletes. *American Journal of Sports Medicine* **34**(9), 1500–1507.

Rettig, A.C. (1998) Epidemiology of hand and wrist injuries in sports. *Clinics in Sports Medicine* **17**(3), 401–406.

Roberts, P.D.T., Geljon, A.C. & Kolt, G.S. (1995) A comparison of retrospective and prospective injury data on Australian rules football and field hockey participants. *Australian Conference of Science and Medicine in Sport*, Hotel Grand Chancellor, Hobart, 17–20 October 1995, Sports Medicine Australia, Canberra, Australia p. 2.

Rose, C.P. (1981) Injuries in women's field hockey: a four-year study. *Physician and Sportsmedicine* **9**(3), 97–98,100.

Sherker, S. & Cassell, E. (1998) *Report No. 143: A review of field hockey injuries and countermeasures for prevention*. Monash University Accident Research Centre, Clayton, Victoria, Australia.

Spedding, I. (1986) Is there a risk of injury in modern hockey? *Sports Coach* **10**(1), 3–4.

Sward, L., Hellstrom, M., Jacobsson, B. & Peterson, L. (1988) Back pain and radiologic changes in the thoraco-lumbar spine of athletes. *American Journal of Sports Medicine* **16**, 530–533.

Verhagen, E.A., van Mechelen, W. & de Vente, W. (2000) The effect of preventive measures on the incidence of ankle sprains. *Clinical Journal of Sports Medicine* **10**(4), 291–296.

Westbrook, K.L. (2000) *Injuries in elite Canadian women's field hockey*. Thesis. University of Alberta, Edmonton, Alberta.

Yard, E.E. & Comstock, R.D. (2006) Injuries sustained by pediatric ice hockey, lacrosse and field hockey athletes presenting to United States emergency departments, 1990–2003. *Journal of Athletic Training* **41**(4), 441–449.

Chapter 12

Gymnastics

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Introduction

Gymnastics is a broad term used to describe a range of physical activities dating back to the Egyptians in 2000 B.C. Several other ancient societies (e.g., Greeks, Romans, Chinese) have also documented various types of gymnastics in relation to conditioning and health. For example, the Chinese participated in gymnastics as mass displays of free exercises. The more modern competitive gymnastics is based on the work of Freidrich Jahn, who developed apparatus including rings, parallel bars, pommel horse, and horizontal bar, with the primary purpose of developing and training strength.

Gymnastics developed further to the point in 1881 at which representatives from France, Holland, and Belgium formed the European Gymnastics Federation, an organization that ran regular world championship competitions. In 1921, this organization changed its name to the Federation International de Gymnastique, which currently remains the world governing body representing approximately 130 member nations. Gymnastics was included in the first modern Olympic Games in Athens in 1896. Although women were not included at this stage, 18 gymnasts from five countries took part in six events (pommel horse, vaulting, rings, horizontal bar, parallel bars, and rope climb). By 1932, floor exercise was also included.

The 1928 Olympic Games saw the introduction of a team event for women, and by the Games of Helsinki in 1952, individual Olympic events for women were introduced, and they have remained ever since. In 1932 the Federation International de Gymnastique conducted the first Artistic Men's World Championships in Paris, which included events for vaulting, bars, and beam, as well as other disciplines, including long jump and javelin. The first participation of women in the World Championships occurred in 1934 in Budapest. Also in Budapest (in 1963), the first World Championships in Modern Gymnastics (to become Rhythmic Sportive Gymnastics in 1975) was held. It was not until 1984 that this gymnastics discipline was introduced to the Olympic Games.

Gymnastics has developed to include several disciplines. Aside from the better-known men's artistic gymnastics, women's artistic gymnastics, and rhythmic sportive gymnastics, the Federation International de Gymnastique also oversees gymnastics for all (a noncompetitive discipline), trampoline gymnastics (since 1998), aerobic gymnastics (since 1996, and formerly known as sport aerobics), and sports acrobatics (since 1999). Current-day Olympic Games include men's gymnastics, women's gymnastics, rhythmic gymnastics, and trampoline gymnastics.

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Gymnastics is a sport that is well known for its intense training, relatively young age of participants, psychological demands, and physical requirements in terms of strength, power, and flexibility. From a biomechanical perspective, a small, lean, and muscular physique provides an advantage in the complex maneuvers that characterize modern-day gymnastics. As such, many performers are entering gymnastics at increasingly younger ages to take advantage of such body shape before the onset of puberty. Added to this is the intense training at such ages, often for up to 20 to 40 hours per week (Caine et al. 1989; Dixon & Fricker 1993; Kolt & Kirkby 1995). In men's gymnastics, training will often commence at older ages, but training intensity will be equally as demanding as for women's gymnastics. Usually men will endure such training levels for longer periods of time given that their peak performance is often of a later onset because of the requirement for greater levels of strength that occur well after puberty.

A further important change in gymnastics in past years has been the complexity and range of skills that have come into the sport. With changes in equipment design (e.g., introduction of sprung floors), the variety of skills, as well as the difficulty and risk associated with such skills (e.g., with a greater number of rotations and twists, and with a higher amplitude) has increased dramatically. Given these factors of intense training during periods of growth and development, and the increased risk of more contemporary maneuvers, it is perhaps not surprising that concern has often been raised regarding the rate and severity of injury in competitive artistic gymnastics (Caine et al. 2008).

Several comprehensive reviews of gymnastics injuries (Caine 2003; Caine & Nassar 2005; Caine et al. 1996) and injury countermeasures (Daly et al. 2001) have been published. It is the intent of this chapter not to simply provide a further review of the same material, but rather to extend on those previous reviews with more recently published work. To build the overall picture, however, material previously reviewed will be included to a lesser degree to provide a complete picture. The predominant focus of the chapter will be on competitive men's and women's artistic gymnastics, and we will provide information on the epidemiology of artistic gymnastics injury as reported in the literature. The majority of the emphasis of this chapter will be on the cross sectional, retrospective, and prospective epidemiologic studies, as they provide very useful information on the distribution and determinants of injury. Case studies (of which there are a large number in the literature) will be drawn on only to discuss particular aspects of injuries, as in general, they do not represent overall gymnastic populations, and cannot be used to identify injury risk.

Much of the extant literature on injury in gymnastics has dealt with female gymnasts, with only a few studies addressing male gymnasts. In reviewing existing literature, several methodologic limitations are apparent, often making comparison between studies difficult (Caine, 2003):

- Diversity of study populations in aspects such as age, level of performance, and type of training environment (e.g., club-based vs. college-based, elite vs. subelite and recreational).
- In many cases, data collection has covered less than a full-year cycle of training and competition. With differences in injury incidence between training and competition (Bak et al. 1994; Caine et al. 1989, 2003; Kerr & Minden 1988; Lindner & Caine 1990a; Marshall et al. 2007; Pettrone & Ricciardelli 1987), comparing different periods of an annual performance and training cycle is difficult and can be seen as problematic.
- Many studies have an insufficient sample size to carry out risk-factor analysis
- Frequent use of self-report questionnaires that may not capture accurate details on the diagnosis and exact nature of injury. Self-report methods also allow gymnasts to present themselves in a way that provides a reason for poor performance (e.g., exaggerate their injuries as a way of accounting for performance)
- The use of retrospective data collection, a method dependent on memory recall and thus the risk of "retrospective contamination." It has been shown that retrospectively collected data tend to miss the more minor injuries, thereby resulting in lower overall injury rates (Kolt & Kirkby 1999).
- Variability in injury definition across studies.

- The use of convenience samples or nonrandom selection, resulting in the possibility that the gymnastic programs most concerned with injury will be overrepresented.
- The dearth of studies on populations from outside North America. With different training methods across countries, findings from one country may not be generalizable to other countries.
- With significant changes in gymnastics training (including increased difficulty of skills being performed), equipment, and rules over the years, comparing results from different periods should be done with caution. For example, every 4 years, rule changes are made in accordance with the Federation International de Gymnastique Code of Points.

It is important for the reader to interpret the findings of gymnastics injury research in light of these limitations, while at the same time recognizing the difficulty of collecting such data in more controlled ways.

Who Is Affected by Injury?

Gymnastics has always been seen as a sport with a high risk of injury, given the nature of the skills being undertaken, as well as the intensity and number of hours of training being undertaken by participants. Defining injury in gymnastics is problematic, however, because of the tendency for gymnasts to train "around" injuries. For example, a gymnast with an ankle injury will often train on bars and avoid mounts and dismounts to protect the ankle. As a result, a commonly recommended definition of injuries in gymnastics studies has been "any gymnastics-related incident that resulted in the gymnast missing any portion of a workout or competitive event" (Caine et al. 1989, 2003). However, there is no published consensus statement endorsing this definition. As a result, there remains considerable variability across studies.

Table 12.1 shows a comparison of injury rates across a large number of prospective and retrospective studies in men's and women's artistic gymnastics. It is clear that that the majority of epidemiologic research on gymnastics injury has been carried out in the 1980s and 1990s, with very little primary research since that time. Comparison of injury rates across studies is difficult, given that most authors have not taken into account the exposure to injury risk, but rather reported injury rates per season. Those who did report injury based on exposure found rates ranging from 0.5 injury per 1,000 hours of participation (Lindner & Caine 1990a) to 5.3 injuries per 1,000 hours of participation (Kolt et al. 2004) for female club gymnasts.

One study of male and female gymnasts in Sweden (Harringe et al. 2007a) found a rate of 2.2 injuries per 1,000 hours of exposure with no sexdifferences. It should be noted that participants in this study were gymnasts involved in "teamgym," a variation of artistic gymnastics involving teams of 6 to 12 members participating in tumbling, trampette, and the floor program. Only two studies have reported data relative to athletic exposures (i.e., one AE equals one athlete participating in a competition or practice) with Caine et al. (2003) finding 8.5 injuries per 1,000 athletic exposures (AEs) in club-level gymnasts and Sands et al. (1993) reporting 90.9 injuries per 1,000 AEs in college-level gymnasts.

Marshall et al. (2007) reported on female gymnastics injuries recorded on the National Collegiate Athletic Association Injury Surveillance System from 1988–1989 through 2003–2004. They found a significant annual decrease in injury rates during competition (−4% annually) over this period, but not during practice. Interestingly, in their retrospective analysis of gymnastics-related injuries treated in U.S. hospital emergency departments, Singh et al. (2008) reported a 25% decrease in the number of injuries between 1990 and 2005.

There is a dearth of injury data for participants in rhythmic gymnastics and trampoline gymnastics. Cupisti et al. (2007b) carried out an 8-month prospective study with 70 club-level rhythmic gymnasts 13 to 19 years of age. They reported 49 significant injuries over the survey period, equating to a rate of 1.08 injuries per 1,000 hours of training.

Where Does Injury Occur?

Anatomical Location

Understanding the anatomical location of injury is important for coaches and sports medicine staff

Table 12.1 Injury rates in women's and men's artistic gymnastics.

Study	Design of Study	Data-Collection Method	Duration of Data Collection	No. of Injuries	No. of Participants[a]	No. of Injuries per 100 Participant-Seasons	No. of Injuries per 1,000 hr of Exposure
Female gymnasts							
Recreational							
Pettrone & Ricciardelli (1987)	P	Q	7 mo	33	2,016	1.6	
Goodway et al. (1989)	P	Q	1 yr	7	5,929	0.1	
Lowry & LeVeau (1982)	R	Q	11 mo	128	3042	4.2	
Club							
Garrick & Requa (1980)	P	Q	1 season	16	72	22.2	
Weiker (1985)	P	Q	9 mo	95	766[b]	12.4	
Vergouwen (1986)	P	I	3 seasons	353	42	840.5	
Pettrone & Ricciardelli (1987)	P	Q	7 mo	29	542	5.3	
Caine et al. (2003)	P	I	1 yr	147	50	294	3.7
Goodway et al. (1989)	P	Q	1 yr	93	725	12.8	
Lindner & Caine (1990a)	P	Q and I	3 seasons	90	362	24.9	0.5
Bak et al. (1994)	P	Q	1 yr	41	46	89	1.4
Kolt & Kirkby (1999)	P and R	Q	18 mo	349	64	364	3.3
Caine et al. (1989)	P	I	3 yr	192	79[c]		2.5
Lowry & LeVeau (1982)	R	Q	11 mo	260	370	70.3	
Steele & White (1983)	R	Q	2 seasons	146	268	54.5	
Backx et al. (1991)	R	Q	7 mo		220		3.6[d]
Dixon & Fricker (1993)	R	I	10 yr	325	162	200	
Kolt & Kirkby (1995)	R	Q	1 yr	321	162	198	2.0
Kolt et al. (2004)	P	Q	9 mo	57	20	2.9	5.3
High school							
Garrick & Requa (1980)							
1973–1975	P	Q and I	2 seasons	39	98	39.8	
1973–1974	P	I	1st			56.0[e]	
1974–1975	P	Q	2nd			28	
Garrick & Requa (1980)	P	Q	1 season	73	221	33	
McLain & Reynolds (1989)	P	I	1 season	11	24	45.8	

(*continued*)

Table 12.1 (*continued*)

Study	Design of Study	Data-Collection Method	Duration of Data Collection	No. of Injuries	No. of Participants[a]	No. of Injuries per 100 Participant-Seasons	No. of Injuries per 1,000 hr of Exposure
College or equivalent							
Marshall et al. (2007)	R	Q	16 yr	2,739	1,380–1,550 per yr[f]		
Harringe et al. (2007)	P	Recorded by physiotherapist	1 season	42	42[g]	100	2.2
Sands et al. (1993)	P	Q	5 yr	509	185	275	
Male gymnasts							
Recreational							
Lowry & LeVeau (1982)	R	Q	11 mo	1	377	0.3	
Club							
Weiker (1985)	P	Q	9 mo	10	107[h]	9.3	
Kerr (1991)	P	Q	8 mo	61	24	254[i]	
Lowry & LeVeau (1982)	R	Q	11 mo	16	21	76.2	
Dixon & Fricker (1993)	R	I	10 yr	247	121	204	
Kirialanis et al. (2003)	P	I	12 mo	151	162[j]	93	
High school							
Garrick & Requa (1980)	P	I	2 seasons	5	18	13.9	
McLain & Reynolds (1989)	P	I	1 season	8	20	40	
College							
NCAA (1994)	P	Q	8 seasons	536			5.33

I = interview; P = prospective; Q = questionnaire; R = retrospective;

Adapted and updated from Caine (2003) and Caine and Nassar (2005). Where no figures are reported, data were not available within the publication or calculations were not possible from the available data.

[a] 1 participant = 1 gymnast participating in one season.

[b] This sample included 477 recreational gymnasts.

[c] Total number of participants during 3 yr (mean duration, 17.5 mo).

[d] Rates include data from 25 male participants.

[e] This rate includes a high incidence of trampoline injuries.

[f] Range of approximate number of participants each year.

[g] This sample includes 16 male gymnasts.

[h] This sample includes 70 recreational gymnasts.

[i] This sample includes data from 8 female gymnasts.

[j] This sample includes 79 female gymnasts.

Table 12.2 Anatomical location of injury in club, high-school, and college artistic gymnastics.

Study	Head (%)	Spine/Trunk (%)	Upper extremity (%)	Lower extremity (%)
Female club gymnasts				
Prospective studies				
Garrick & Requa (1980)	6.0	0.0	25.0	69.0
Weiker (1985)	3.2	7.5	18.1	70.2
Caine et al. (2003)	0.7	15.0	20.5	63.7
Lindner & Caine (1990a)	4.1	16.7	22.9	54.1
Bak et al. (1994)	2.4	9.8	17.1	61.0
Kolt & Kirkby (1999)	1.1	17.2	20.9	59.0
Caine et al. (1989)	1.6	19.2	21.4	57.8
Harringe et al. (2007)		26.9	7.7	65.4
Retrospective studies				
Steele & White (1983)	1.4	13.7	14.4	69.1
Kerr & Minden (1988)		13.0		56.0
Dixon & Fricker (1993)	1.5	22.3	21.7	55.3
Kolt & Kirkby (1995)	0.6	17.8	22.7	57.3
Homer & Mackintosh (1992)	2.0	24.4	18.3	54.9
Female high school and college gymnasts				
Garrick & Requa (1980) (mixed)	3.0	13.0	36.0	48.0
Garrick & Requa (1980) (interscholastic)	7.7	43.6	12.8	35.9
Sands et al. (1993)	0.8	18.1	22.2	58.9
Marshall et al. (2007)	5.6 (practice)[a] 6.7 (competition)	19.1 (practice) 9.5 (competition)	17.8 (practice) 11.5 (competition)	52.8 (practice) 69.3 (competition)
Male gymnasts				
Weiker (1985)	18.2	9.1	36.4	36.4
Kerr (1991)[b]		20.0	23.0	47.0
Dixon & Fricker (1993)	0.4	13.4	53.4	32.8
Lueken et al. (1993	3.2	17.1	39.3	43.1
Kirialanis et al. (2003)[c]	0.0	7.9	19.9	72.2
Harringe et al. (2007)	0.0	31.3	12.5	56.2

Adapted and updated from Caine (2003) and Caine and Nassar (2005). Where no figures are reported, data were not available within the publication or calculations were not possible from the available data.
[a] This study combined head and neck injuries into a single category.
[b] This sample combines 16 men and 8 women.
[c] This sample combines 83 men and 79 women.

alike. Such information highlights the body parts most likely to be injured, and can point to preventive measures, including technique changes and physical conditioning programs. Table 12.2 shows injury by anatomical location for female and male gymnasts at club level and college level. Not all studies of injury in gymnastics report injury by anatomical location, and given the relatively low rates of injury in recreational gymnasts, no classification by anatomical location is provided for these participants.

As shown in Table 12.2, the lower extremity is the most commonly injured body region for both

Figure 12.1 The ankle is one of the most commonly injured body parts in gymnasts. © IOC/Hiroki SUGIMOTO

club-level gymnasts and high-school and college gymnasts (35.9–70.2% of injuries), with the majority of studies finding proportions above 50%. The next most frequently injured region appears to be the upper extremity (7.7–36.0%), the trunk and spine (0–43.6%), and the head (up to 7.7%). There do not appear to be any obvious differences between the proportions reported in prospective and retrospective studies.

A more specific look at these body regions highlights that injuries to the knee are the most common, followed by those to the ankle (Fig. 12.1) and the lower back. For example, knee injuries ranged from 13.5% to 24.5% of all reported injuries in four studies (Steele & White 1983; Weiker 1985; Lindner & Caine 1990a; Kolt & Kirkby 1999), and comprised 26.5% of combined knee and thigh injuries in the Kirialanis et al. (2003) study. Over one-quarter of all competition injuries and 10.6% of all practice injuries in the 16-year longitudinal study of Marshall et al. (2007) involved the knee.

With respect to the ankle, Kerr (1991) found that it accounted for 29.0% of injuries, Garrick and Requa (1980) 25.0%, Kolt and Kirkby (1999) 31.2% (combined ankle and foot), Kirialanis et al. (2003) 45.7% (combined ankle and foot and men and women), and Marshall et al. (2007) 18.8% in competition and 15.2% in practice. The lower back accounted for 12.2% to 20.3% of injuries in four studies of club-level gymnasts (Homer & Mackintosh 1992; Sands et al. 1993; Kolt and Kirkby 1999; Caine et al. 2003), yet only 3.2% of all competition injuries and 7.7% of all practice injuries among college-level gymnasts (Marshall et al. 2007).

Only six studies reported injury to male gymnasts by anatomical location. These included five prospective studies (Weiker 1985; Lueken et al. 1993; Kerr 1991; Kirialanis et al. 2003; Harringe et al. 2007a) and one retrospective study (Dixon & Fricker 1993). Similar to the rate for female gymnasts, the lower extremity appeared to be the most injured region (32.8–72.2% of injuries) followed by the upper limb (12.5–53.4%) and trunk and spine (7.9–31.3%). The Dixon and Fricker (1993) study, however, which examined injuries over a 10-year period, found the upper extremity (53.4% of injuries) to incur more injuries than the lower extremity (32.7%). When examining specific anatomical locations, the shoulder joint was a commonly injured body part, ranging from 4.6% in a small study of 16 male gymnasts (Kirialanis et al. 2007) to 19.1% (Dixon & Fricker 1993). The wrist was also a commonly injured body part, with up to 13.8% of injuries (Dixon & Fricker 1993), as was the ankle, with a range from 9.8% (Dixon & Fricker 1993) to 25.0% (Harringe et al. 2007a) and 27.0% (Kerr 1991). In the Kerr (1991) study, the lower back accounted for 20.0% of injuries. The parts of the upper extremity (e.g., shoulder, wrist) in male gymnasts are more commonly injured than in female gymnasts (in whom ankle and lower back injuries predominate), is likely indicative of the different types of apparatus used in men's gymnastics.

Data on the anatomical location of injury in rhythmic gymnastics is limited. Cupisti et al. (2004) carried out a cross-sectional study of the prevalence of low back pain in 67 club-level rhythmic gymnasts. They found that only 10.5% of gymnasts reported low back pain, as compared with 26.0% of matched controls (nongymnasts). The timing within the season during which the survey was administered may have contributed to what appears a very low prevalence of low back pain in this sample. In a later study, Cupisti et al. (2007) investigated 70 club-level rhythmic gymnasts over an 8-month period. The most prevalent anatomical sites for injury were the foot (38.3%), knee and lower leg (19.1%), and back (17.0%).

Environmental Location

Practice versus Competition

Gymnastics is a sport characterized by a large number of hours dedicated to training and very few hours spent in competition. It is not unusual for some gymnasts, despite training up to 40 hours per week, to participate in only 5 to 10 competitions per year. With this differential in time spent in training versus competition, it is expected that a larger proportion of injuries would occur in a training environment. Although not all studies report distribution of injuries by practice versus competition, several studies of female gymnasts have found that 71.0% to 96.6% of injuries occur in practice and 3.4% to 21.0% in competition (Garrick & Requa 1980; Pettrone & Ricciardelli 1987; Kerr & Minden 1988; Caine et al. 1989, 2003; Lindner & Caine 1990a; Bak et al. 1994; Harringe et al. 2007a). However, when exposure is accounted for, the rate of injury has been shown to be two to three times greater in competition (Caine et al. 2003; Marshall et al. 2007).

Gymnastic Events

With gymnasts participating in a wide variety of events or apparatus (six for men, four for women, and many other nonapparatus training drills), it is important to understand where the greatest risk of injury lies. However, much of the injury data reported for gymnastics fail to differentiate between sudden-onset and gradual-onset injuries, and also does not take into account exposure time on each apparatus; these combined factors make it difficult to accurately understand the relationship between gymnastic event and injury. In one study that did report exposure-based acute injury data, Caine et al. (2003) found that the floor exercise was the event most likely to lead to injury in club-level female gymnasts. This supported an earlier finding that floor exercise had the highest frequency of injury at international competitions in the period from 1983 to 1998 (Leglise 1998).

In men's gymnastics, few data are available. Kirialanis et al. (2003) found that 52.9% of all knee injuries and 43.8% of all ankle injuries occurred on floor exercise, and that 37.5% of ankle injuries were incurred during work on the parallel bars. In an earlier study, Lueken et al. (1993) found that from 15 years of injury data taken from the U.S. Olympic Training Center, floor exercise contributed most to injury (24.9%), followed by rings (19.2%), horizontal bar (16.9%), parallel bars (16.4%), pommel horse (14.7%), and vault (7.9%). NCCA data for 1987 through 1994 (NCCA 1994) also show floor exercise as having the highest percent of injuries (27.9%), followed by high bar (22.1%) and pommel horse (27.6%).

When Does Injury Occur?

Injury Onset

In gymnastics, in which a high number of training hours are required for high-level performance and a number of high-risk skills are performed, it is expected that both sudden-onset and gradual-onset injuries will occur. Studies reporting on injury onset for female gymnasts indicate a range of 21.9% to 55.8% for gradual-onset and 44.2% to 82.3% for sudden-onset injuries (Steele & White 1983; Weiker 1985; Pettrone & Ricciardelli 1987; Goodway et al. 1989; Caine et al. 1989, 2003; Lindner & Caine 1990a; Jones 1992; Dixon & Fricker 1993; Mackie & Taunton 1994; Bak et al. 1994; Kolt & Kirkby 1995, 1999; Harringe et al. 2007b). In all but one study (Caine et al. 1989), the greatest proportion of injuries were of sudden onset. Studies of male gymnasts also show a greater proportion of sudden- versus gradual-onset injuries (Kerr 1991; Dixon & Fricker, 1993; Kirialanis et al. 2003).

Some studies also suggest that higher-level gymnasts tend to have a greater proportion of gradual-onset or chronic injuries. For example, Kolt and Kirkby (1995) in their retrospective study showed that 55.0% of injuries to elite gymnasts were of gradual onset, as compared with only 34.3% for their subelite counterparts. In a later longitudinal study, Kolt and Kirkby (1999) found that 49.7% of elite gymnasts' injuries were of gradual onset, as compared with only 25.0% for the subelite group. This supports earlier findings from highly competitive and trained gymnasts, in which 55.8% of injuries were gradual in onset (Caine et al. 1989).

Chronometry

When examining injury chronometry in gymnastics, both timing within a practice session and timing during a year-long season are important. Although not many studies have reported this level of detail in describing injury, it does provide very useful information for designing practice sessions and outlining annual training programs. Several studies have reported that the early part of a training session is a period during which a higher frequency of injury can occur (Caine et al. 1989, 2003; Lindner & Caine, 1990a). In a more recent study of male and female gymnasts, Harringe et al. (2007a) reported that 26% of all training injuries occurred at the beginning of the session, 24% at midsession, 33% toward the end of the session, and 17% with a gradual increase throughout the whole session. One study investigated the time into a competition when injury occurred (Caine et al. 2003) and found that 58.3% of such injuries occurred during the first half-hour of a competition.

A number of studies have also followed the time into the season for injury occurrence in women's gymnastics (Caine et al. 1989, 2003; Kerr & Minden 1988; Dixon & Fricker 1993; Marshall et al. 2007). The findings of these studies vary, but it appears that injury rates can increase following periods of decreased training (Caine et al., 1989, 2003), during the practice of competitive routines (Caine et al. 1989; Sands et al. 1993), and during weeks just prior to and during competition (Kerr & Minden 1988; Sands et al., 1993; Caine et al. 2003). Similarly, Singh et al. (2008) reported a peak frequency of gymnastics-related injuries presenting to U.S. hospital emergency departments during October and March, months that are associated with the competitive seasons for club gymnastics and high-school gymnastics, respectively. The most comprehensive study in this area demonstrated that in-season competition rates were higher than postseason injury rates (15.6 vs. 10.8 injuries per 1,000 AEs) (Marshall et al. 2007).

What Is the Outcome?

Injury Type

Injury types in gymnastics have been categorized differently across studies, making comparison difficult. Table 12.3 shows a percent comparison of injury types across a range of studies of female gymnasts. It can be seen from the table that sprains (15.9–43.6%) are the most common type of injury, followed by strains (6.4–31.8%). Other types of injuries that are common in some studies include contusions (Garrick & Requa 1980; Lowry & LeVeau 1982), fractures (Garrick & Requa 1980; Pettrone & Ricciardelli 1987), and inflammatory conditions (Kolt & Kirkby 1995, 1999). The main difficulties in comparing the proportions across studies are differences in understanding and definition of the injury types, and the self-report nature of data collection in some studies.

We found one report on injury types for male gymnasts. In the 1993–1994 NCAA Injury Surveillance System Report for Gymnastics, the top three injury types during 1986 through 1994 were sprain (22–35%), strain (12–26%), contusion (7–17%), and fracture (7–12%) (NCAA 1994).

For rhythmic gymnastics, only one study has reported injury type (Cupisti et al. 2007). They found that of the 46 injuries recorded, 26.1% were strains, 15.2% sprains, 17.4% contusions, 6.5% fractures, 2.2% dislocations, and 32.6% other.

Time Loss

Most studies that recorded this level of data have found that mean time loss per injury is greater for advanced than for lower-level gymnasts (Kolt &

Table 12.3 Type of injury in recreational, club, high-school, and college female artistic gymnastics.

Level/Study	Abrasion	Concussion	Contusion	Dislocation	Fracture	Inflammation	Laceration	Nonspecific	Sprain	Strain	Other
Recreational											
Retrospective studies											
Lowry & LeVeau (1992)	0.0	0.0	27.3	1.6	3.0	11.7	2.3	0.0	32.0	21.0	0.0
Club											
Prospective studies											
Garrick & Requa (1980)			0.0		31.2				15.9	16.2	18.7
Pettrone & Ricciardelli (1987)[a]	0.0	0.0	9.7	6.4	27.4	8.1	0.0	0.0	41.9	6.4	0.0
Caine et al. (1989)	0.0	0.7	4.1	0.7	3.4	10.2	0.0	40.1	19.0	17.7	4.1
Lindner & Caine (1990a)	2.2	0.0	6.5	4.3	4.8	6.5	1.1	11.8	19.4	11.8	9.7
Kolt & Kirkby (1999)	0.0	0.0	6.0	0.6	8.3	17.9			29.7	23.3	14.3
Caine et al. (2003)	0.5	0.5	8.9	0.5	1.6	3.1	1.6		19.3	31.8	29.2
Retrospective											
Lowry & LeVeau (1992)	0.0	0.0	34.2	1.5	8.1	13.8	0.0	0.0	41.9	20.6	21.4
Kolt & Kirkby (1995)			3.1	1.6	8.4	15.3			29.6	20.6	21.4
High school											
Prospective studies											
Garrick & Requa (1990)											
1 year (mixed study)			4.1		8.2				39.7	31.5	16.4
2 year (interscholastic study)			20.5		0.0				43.6	17.9	17.9

Adapted and updated from Caine (2003) and Caine and Nassar (2005). Where no figures are reported, data were not available within the publication or calculations were not possible from the available data.

[a] Includes data for recreational as well as club-level gymnasts.

Kirkby 1995, 1999; Caine et al. 2003). For example, Kolt and Kirby (1999) reported that female elite gymnasts missed 0.5 training session and modified 23.1 training sessions per injury, whereas their subelite counterparts missed 2.0 and modified 7.0 training sessions for each injury. When viewing this impact from an annual perspective, Kolt and Kirkby (1999) found that elite gymnasts spent 21% of their total annual training time participating at a reduced capacity because of injury, with subelite (although competitive) gymnasts reducing their training capacity by 16.5%. In an earlier study, Sands et al (1993) did not comment directly on the time lost due to injury but did find that female college gymnasts were training with an injury during approximately 71% of training sessions.

Other studies that have looked at the number of days lost due to injury have found that advanced-level participants experience a greater proportion of severe injuries ($\geqslant$ 21 days time loss) than beginning-level female gymnasts (17% vs. 3%; Fisher's exact $P = 0.003$) (Caine et al. 2003) and that competition injuries resulted in a greater proportion of severe injuries than those that occurred in practice (37.5% vs. 10.2%; Fisher's exact $P = 0.007$) (Caine et al. 2003). Kirialanis et al. (2003), in a sample of male and female gymnasts, found that 29% of injuries resulted in absence from training and competition for >1 month, and a further 44% of injuries resulted in absence for between 1 week and 1 month. Perhaps the strongest data in this area come from the 16-year study of injuries in female college gymnasts (Marshall et al. 2007). Over this 16-year period, 39% of competition injuries and 32% of training injuries resulted in a time loss $\geqslant$10 days.

For competitive rhythmic gymnasts, Cupisti et al. (2007) found that for each injury sustained, 4.1 training sessions were missed and 32 were modified.

Clinical Outcome

Recurrent Injury

Gymnastics is a sport in which participants experience recurrent injuries for several reasons including premature return to activity, inadequate rehabilitation, and possibly an underestimation of the severity of the primary injury (Kolt & Kirkby 1999). The repetitive nature of training for many gymnastic skills is also likely a reason for the predominance of recurrent injuries. Several cohort studies of female competitive gymnasts found that between 24.5 and 32.3% of all injuries were reinjuries (Linder & Caine 1990; Kolt & Kirkby 1999; Caine et al. 2003). It has also been shown that club-level (2.1 reinjuries per 1,000 AEs; Caine et al. 2003) and college-level (2.19 reinjuries per 1,000 AEs; NCAA 1994) gymnasts show similar rates of reinjury. No recent published data are available on rates of recurrent injury, nor are there any data available for male gymnasts.

Catastrophic Injury

There is concern in gymnastics regarding catastrophic injury given the high-risk skills being trained and competed. There have been some highly publicized spinal cord injuries to gymnasts from China (Cowley & Westly 1998) and the United States (Ryan 1995). The national spinal cord injury registry in Japan identified seven catastrophic injuries to female gymnasts from 1990 to 1992 (Katoh et al. 1996), and Schmitt and Gerner (2001) reported six female gymnasts with spinal cord injuries over the period 1985 to 1997.

Data arising from studies of club-level gymnasts indicate an infrequent occurrence of catastrophic injury. Dixon and Fricker (1993), in a retrospective study of 116 male and female elite gymnasts training at the national sports institute in Australia, found no catastrophic (life-threatening) injuries over the 10-year period of interest. These findings are supported by other longitudinal studies of club-level gymnasts (Caine et al. 1989, 2003; Lindner & Caine 1990a; Kolt & Kirkby 1999) showing no catastrophic injuries. Unfortunately, there are currently no national injury surveillance systems that track injuries, including catastrophic injuries, among club-level gymnasts.

Other available data have shown a relatively small number of catastrophic injuries relative to the number of participants. The National Center for Catastrophic Sports Injury Research (2007) has tracked catastrophic injuries in high-school and college settings since 1982. In the period 1982 to 2007, there were 19 catastrophic injuries occurred among more than 147 million high-school and 8 million college gymnast participants. In comparison to other sports, direct injury rates for nonfatal (i.e., permanent, severe functional disability such as quadriplegia) were highest for male and female gymnasts at both the high-school and college levels.

Nonparticipation

Injury is often a reason for dropping out of sport. Dixon and Fricker (1993) in their study of Australian elite gymnasts over 10 years found that 9.5% retired as a result of injury. The sorts of injuries that were involved in the decision to drop out included anterior cruciate ligament rupture, osteochondritis of the elbow, knee meniscus lesions, navicular stress fracture, and chronic rotator-cuff conditions. Some published case studies have also reported injuries that led to withdrawal from gymnastics. These included injuries to the low back (Katz & Scerpella, 2003) and elbow (Jackson et al. 1989; Maffulli et al. 1992; Singer & Roy 1984). Other studies that have examined the relationship between injury and dropping out of a sport have found that between 16.3% and 52.4% of those who dropped out of club-level gymnastics had an injury at the time of withdrawing from the sport (Caine et al. 1989, 2003; Lindholm et al. 1994). Although this could suggest that injury may have played a role in the withdrawal, there are several other factors, such as age or transition to other sports that could have influenced this decision. Notably, data on 80 youths who had dropped out of club-level gymnastics within the previous month indicated that being injured was the least important factor in their decision to drop out (Kolt 1996).

Residual Effects

Despite the high rates of injury in gymnasts and the severity of a large proportion of those injuries, very few studies have examined the residual or longer-term effects of such injuries. In the earliest of these, Wadley and Albright (1993) surveyed former collegiate gymnasts and found that 45% of previous injuries (low back, ankle, great toe, shoulder, knee) still had symptoms. Two studies focused on back pain and associated radiologic changes in former top-level gymnasts (Tsai & Wredmark 1993; Lundin et al. 2001). These studies found no differences between the former gymnasts and control groups (nongymnasts) in back pain, but reported a higher prevalence in radiologic changes (e.g., degenerative changes) in the gymnastic groups. Maffulli et al. (1992) carried out long-term follow-ups (mean, 3.6 years) of elbow joint articular surface lesions in 12 (6 male and 6 female) gymnasts. They found a high frequency of osteochondritic lesions, signs of joint aging, loose intraarticular bodies, decreased range of elbow extension, and mild residual pain at full extension.

What Are the Risk Factors?

For injury-intervention and rehabilitation programs to be effective, an in-depth knowledge of injury risk factors is paramount.

Intrinsic Factors

Some studies showed that body size (height and weight), age, and body fat were all greater in injured or high-injury-risk gymnasts (Steele & White 1983; Lindner & Caine 1990a, 1993; DiFiori et al. 2002a). It is possible, however, in these studies that factors such as greater height and weight characterized older gymnasts who were competing at higher levels of competition.

Results of a study of gymnastics-related injuries presenting to U.S. hospital emergency departments suggests an age effect with regard to distribution of injuries. Singh et al. (2008) reported that upper-extremity injuries were more common in the 6-to-11-year age group than in the 12-to-17-year age group (risk ratio, 1.46; 95% confidence interval [CI], 1.37–1.56; $P < 0.0001$) and that lower-extremity injuries were more common in the 12-to-17-year age group (risk ratio, 1.69; 95% CI, 1.56–1.83;

$P < 0.0001$). Also, the 6-to-11-year-olds were more likely to be admitted than the 12-to-17-year-olds (risk ratio, 1.69; 95% CI, 1.23–2.32; $P > 0.001$).

Some research also indicates that a rapid period of growth is associated with increased risk of injury (Caine & Lindner 1985; Micheli 1983). Caine et al. (1989) found that rapid growth (as indicated by Tanner stages) was associated with increased risk of injury ($P < 0.05$). Caine et al. (2006) also reported previous injury (incidence rate ratios [IRR], 1.55; 95% CI, 1.79–2.0), injury to other sites (incidence rate ratios [IRR], 155; 0.74; 95% CI, 0.65–0.85), and positive musculoskeletal assessment (i.e., symptomatic during preseason musculoskeletal assessment; IRR, 1.49; 95% CI, 1.24–1.79) to be predictors of overuse but not acute injury among highly competitive female gymnasts.

Motor characteristics such as less speed, poorer balance, higher endurance, and higher flexibility have been implicated as significant injury predictors in female gymnasts (Lindner & Caine 1990b). Steele and White (1983) suggested that high lumbar flexibility and low shoulder flexibility were associated with risk of injury. These joint ranges of motion were, however, taken after injury, so the direction of the association cannot be determined.

An interesting but underresearched area of injury risk in gymnastics is the role played by psychosocial factors. Kerr and Minden (1988) and Kolt and Kirkby (1996) showed that increased levels of life stress were associated with the number of injuries and their severity. The retrospective nature of these studies, however, means that the direction of the relationship between life stress and injury cannot be accurately determined. Petrie (1992), in a prospective study of 193 female gymnasts, found that those who were injured reported higher negative life stress than their noninjured counterparts.

Extrinsic Factors

Training and competition exposure is the most common extrinsic risk factor for injury. The results of research are still somewhat inconclusive as to whether advanced or lower levels of training and competition pose the greatest risk for highest injury rate (Caine et al. 1989, 2003; Kolt & Kirkby 1995, 1999). Two of these studies indicate lower injury rates for elite than for subelite gymnasts (Kolt & Kirkby 1995, 1999). Using the proportion of time loss and injury rate as criterion variables (Caine et al. 1989), competitive level was the best discriminator between high- and low-risk gymnasts. Caine et al. (2003) showed that advanced gymnasts were at increased risk of injury as compared with beginning-level gymnasts (risk ratio, 1.47; 95% CI, 0.92–2.33). This difference was even greater for competition (risk ratio, 4.22; 95% CI, 1.33–13.36) than for practice (risk ratio, 0.97; 95% CI, 0.34–2.75). The 16-year study by Marshall et al. (2007) also found that competition injury rates were higher in those competing in higher-level versus lower-level divisions (16.6 injuries per 1,000 AEs vs. 7.6).

What Are the Inciting Events?

Very few studies provide information on the action or activity leading to injury in gymnastics. Harringe et al. (2007a) reported that 52% of injuries occurred during landing and 21.5% during takeoff for tumbling and vaulting. In a different form of classification, a study of 16 years of data (Marshall et al. 2007) showed that for competition injuries, 70.7% resulted from either landings in floor exercise or from dismounts from other apparatus. Marshall et al. (2007) also reported that the majority of injuries in practice (54%) and competition (70.7%) involved other contact—contact with items such as the floor, the mat, or equipment.

In their 3-year study of Canadian gymnasts, Lindner and Caine (1990) reported that the most frequent mechanism of sudden-onset injuries was a missed move followed by contact with or fall from apparatus. They did not, however, specify whether the missed move involved contact with apparatus or floor.

Injury Prevention

A summary of suggested preventive measures has been provided in several reviews on gymnastics injuries (Daly et al. 2001; Caine 2003; Caine &

Nassar 2005). Most of these measures emerged from clinical practice or descriptive research, and some from risk factor analyses, but none of them have actually been tested to determine their effectiveness. In contrast, there has been promising research in other sports areas (e.g., team handball, soccer, basketball) supporting the use of injury-prevention strategies that include preseason conditioning, functional training, education, and strength and balance programs that are continued throughout the playing season (Heidt et al. 2000; Wedderkopp et al. 2003; Olsen et al. 2005; McGuine & Keene 2006; Mickel et al. 2006; Emery et al. 2007).

The results of prevention studies in women's gymnastics are encouraging. Although not statistically evaluated, one study using a three-step protocol involving postural, proprioceptive, and postural components, shows promise in reducing ankle and low back pain in young elite female gymnasts (Mirca et al. 2008). In addition, Harringe et al. (2007) conducted an 8-week lumbar stabilizing intervention (nonrandomized) involving 51 gymnasts, 11 to 16 years of age. Gymnasts in the intervention group reported significantly few days with back pain at completion as compared with baseline ($P = 0.02$).

Given the numerous causes of injury in gymnastics, preventive measures are no doubt complex. To be effective, it is clear that input is needed from the gymnast, coach, policy and rule makers, equipment manufacturers, and a multidisciplinary medical support team (including athletic trainers, physical therapists, physicians, psychologists, and nutritionists).

Further Research

In an extensive review such as this, it is often the case that a greater number of areas needing research are exposed than the amount of research carried out to date. Several critical areas of research have been identified for gymnastics.

- Further work on injury in relation to exposure-time data is required. To date, only a few studies have looked at injury in light of the amount of time gymnasts spend in training and competition.
- Much of the injury research occurred in the 1980s and 1990s, with very little since that time. With significant changes in gymnastics over the past 10 to 15 years (including equipment changes and rule changes), data on current-day gymnasts are required. In this regard, nationally organized injury surveillance programs are needed.
- Research on injury in male gymnasts is clearly lacking and needs attention. This should specifically include epidemiologic and analytic risk-factor studies.
- Research on injury in rhythmic gymnastics is clearly lacking and needs attention. With very different physical demands on artistic gymnastics, relying on generalization of findings across disciplines is not advised. Both epidemiologic and risk-factor studies are required.
- There is an absence of research specifically on trampoline gymnastics. As this discipline becomes more popular, research findings from epidemiologic studies will be required to help guide training and injury prevention and rehabilitation.
- Further research is required on the residual effects of injuries later in life. With many gymnastics injuries being significant or long-term in nature, it is important to ascertain the longer-term effects of such events.
- More accurate research on predictors and risk factors of injury in gymnastics is needed. This research should be done prospectively and should encompass modifiable risk factors that could be developed into injury-prevention strategies. Risk factors of particular interest include injury history, pain history, coaching qualifications, periods of rapid growth, and psychosocial factors.
- Because most of the research to date has relied on self-report of injury, medical evaluation of injury is required to more accurately categorize and diagnose injuries.
- There is a pressing need for studies designed to identify and determine the effect of injury-prevention

measures on reducing the rate of injury among gymnasts. Injury-prevention measures of particular interest include neuromuscular training programs, preseason conditioning, programs to enhance landing and skill mechanics, and use of taping and bracing to prevent ankle injuries.

Future research will be successful in its outcomes and applications only if truly collaborative efforts are put in place. Potential contributors of effective research teams include the coach, physician, physical therapist, athletic trainer, epidemiologist, and research academicians.

References

Backx, F.J.G., Beijer, H.J.M., Bol E. & Erick, W.B.M. (1991) Injuries in high-risk persons and high-risk sports: a longitudinal study of 1818 school children. *American Journal of Sports Medicine* **19**,124–130.

Bak, K., Kalms, S.B., Olesen, J. & Jurgensen, U. (1994) Epidemiology of injuries in gymnastics. *Scandinavian Journal of Medicine and Science in Sports* **4**,148–154.

Caine, D., Cochrane, B., Caine, C. & Zemper, E. (1989) An epidemiological investigation of injuries affecting young competitive female gymnasts. *American Journal of Sports Medicine* **17**, 811–820.

Caine, D., Knutzen, K., Howe, W., Keeler, L., Sheppard, L., Henrichs, D. & Fast, J. (2003) A three-year epidemiological study of injuries affecting young female gymnasts. *Physical Therapy in Sport* **4**, 10–23.

Caine, D. & Lindner, K. (1985) Overuse injuries of growing bones: the young female gymnast at risk. *Physician and Sportsmedicine* **13**, 51–62.

Caine, D., Maffulli, N. & Caine, C. (2008). Epidemiology of injury in child and adolescent sports: injury rates, risk factors, and prevention. *Clinics in Sports Medicine* **27**, 19–50.

Caine, D.J. (2003) Injury epidemiology. In: *Scientific Aspects of Women's Gymnastics,* vol. 35 of *Medicine and Sport Science* (Sands, W.A., Caine, D.J. & Borms, J.), Basel, Karger, pp. 72–109.

Caine, D.J., Daly, R.M., Jolly, D., Hagel, B.E. & Cochrane, B. (2006) Risk factors in young competitive female gymnasts. *British Journal of Sports Medicine* **40**, 90–91.

Caine, D.J., Lindner, K.J., Mandelbaum, B.R. & Sands, W.A. (1996) Gymnastics. In: *Epidemiology of Sports Injuries* (Caine, D.J., Caine, C.G. & Lindner, K.J., eds.), Human Kinetics, Champaign, IL.

Caine, D.J. & Nassar, L. (2005) Gymnastics injuries. In: *Epidemiology of Pediatric Sports Injuries: Individual Sports.* vol. 48 of *Medicine and Sport Science* (Caine, D.J. & Maffulli, N., eds.), Basel, Karger, pp. 18–58.

Cowley, J. & Westly, M. (1998) A gymnast's long fall: a minor misstep leaves China's best vaulter paralysed: can new drugs help her walk again? *Newsweek*, August 3, p. 56.

Cupisti, A., D'Alessandro, C., Evangelisti, I., Piazza, M., Galetta, F. & Morelli, E. (2004) Low back pain in competitive rhythmic gymnasts. *Journal of Sports Medicine and Physical Fitness* **44**, 49–53.

Cupisti, A., D'Alessandro, C., Evangelisti, I., Unbri, C., Rossi, M., Galetta, F., Panicucci, E., Lopes Pegna, S. & Piazza, M. (2007) Injury survey in competitive sub-elite rhythmic gymnasts: results from a prospective controlled study. *Journal of Sports Medicine and Physical Fitness* **47**, 203–207.

Daly, R.M., Bass, S.L. & Finch, C.M. (2001) Balancing the risk of injury to gymnasts: how effective are the countermeasures? *British Journal of Sports Medicine* **35**, 8–20.

DiFiori, J.P., Puffer, J.C., Aish, B. & Dorey, F. (2002a) Wrist pain in young gymnasts: Frequency and effects upon training over 1 year. *Clinical Journal of Sports Medicine* **12**, 348–353.

DiFiori, J.P., Puffer, J.C., Aish, B. & Dorey, F. (2002b) Wrist pain, distal radial physeal injury and ulnar variance in young gymnasts: does a relationship exist? *American Journal of Sports Medicine* **30**, 879–885.

Dixon, M. & Fricker, P. (1993) Injuries to elite gymnasts over 10 yr. *Medicine and Science in Sports and Exercise* **25**, 1322–1329.

Emery, C.A., Rose, M.S., McAllister, J.R. & Meeuwisse, W.H. (2007) A prevention strategy to reduce the incidence of injury in high school basketball: a cluster randomized controlled trial. *Clinical Journal of Sports Medicine* **17**, 17–24.

Garrick, J.G. & Requa, R.K. (1980) Epidemiology of womenís gymnastics injuries. *American Journal of Sports Medicine* **8**, 261–264.

Goodway, J.D., McNaught-Davis, J.P. & White, J. (1989) The distribution of injuries among young female gymnasts in relation to selected training and environmental factors. In: *Children and Exercise XIV: Band 4* (Beunen, G., ed.), Schriftenreihe der Hamburg-Mannheimer-Stiftung fur Informationsmedizeft Enke Verlag.

Harringe, M.L., Renström, P. & Werber, S. (2007a) Injury incidence, mechanism and diagnosis in top-level teamgym: a prospective study conducted over one season. *Scandinavian Journal of Medicine and Science in Sports* **17**, 115–119.

Harringe, M.D., Hordgren, J.S, Arvidsson, L., Werner, S. (2007b). Low back pain in young female gymnasts and the effect of specific segmental muscle control exercises of the lumbar spine: a prospective controlled intervention study. *Knee Surgery, Sports Traumatology, and Arthroscopy* **15**, 1264–1271.

Heidt, R.S., Sweeterman, L.M., Carlonas, R.L., Traub, J.A. & Tekulve, F.X. (2000) Avoidance of soccer injuries with preseason conditioning. *American Journal of Sports Medicine* **28**, 659–662.

Homer, S. & Mackintosh, S. (1992) Injuries in young female elite gymnasts. *Physiotherapy* **78**, 804–808.

Jackson, D.W., Silvino, N. & Reiman, P. (1989) Osteochondritis in the female gymnast's elbow. *Arthroscopy* **5**, 129–136.

Jones, A. (1992) *Training of young athletes study,* The Sports Council, London.

Katoh, S., Shigu, H., Itaka, T. & Iwatsubo, E. (1996) Sports-related spinal cord injury in Japan. *Spinal Cord* **34**, 416–421.

Katz, D.A. & Scerpella, T.A. (2003) Anterior and middle column thoracolumbar spine injuries in young female gymnasts: report on seven cases and review of the literature. *American Journal of Sports Medicine* **31**, 611–616.

Kerr, G.A. (1991) Injuries in artistic gymnastics. *Journal of the Canadian Athletic Therapists Association* **April**, 19–21.

Kerr, G.A. & Minden, H. (1988) Psychological factors related to the occurrence of athletic injuries. *Journal of Sport and Exercise Psychology* **10**, 167–173.

Kirialanis, P., Malliou, P., Beneka, A. & Giannakopoulos, K. (2003) Occurrence of acute lower limb injuries in artistic gymnasts in relation to event and exercise phase. *British Journal of Sports Medicine* **37**, 137–139.

Kolt, G.S. (1996) *Psychological aspects of gymnastic injury, performance, and participation*. Dissertation, La Trobe University, Australia.

Kolt, G.S., Hume, P.A., Smith, P. & Williams, M.W. (2004) Effects of a stress-management program on injury and stress of competitive gymnasts. *Perceptual and Motor Skills* **99**, 195–207.

Kolt, G.S. & Kirkby, R.J. (1995) Epidemiology of injuries in Australian female gymnasts. *Sports Medicine, Training and Rehabilitation* **6**, 223–231.

Kolt, G.S. & Kirkby, R. (1996) Injury in Australian competitive gymnasts: a psychological perspective. *Australian Journal of Physiotherapy* **42**, 121–126.

Kolt, G.S. & Kirkby, R.J. (1999) Epidemiology of injury in elite and subelite female gymnasts: a comparison of retrospective and prospective findings. *British Journal of Sports Medicine* **33**, 312–316.

Leglise, M. (1998) Limits on young gymnasts' involvement in high-level sport. *Technique* **18**(4).

Lindholm, C., Hagenfeldt, K. & Ringertz, B.M. (1994) Pubertal development in elite juvenile gymnasts: effects of physical training. *Acta Obstetricia et Gynecologica Scandinavica* **73**, 269–273.

Lindner, K.J. & Caine, D. (1990a) Injury patterns of female competitive club gymnasts. *Canadian Journal of Sport Sciences* **15**, 254–261.

Lindner, K.J. & Caine, D. (1990b) Injury predictors among female gymnasts' anthropometric and performance characteristics. In: *Sports, Medicine and Health* (Hermans, G.P., & Mosterd, W.L., eds.), Excerpta Medica, Amsterdam, pp. 136–141.

Lindner, K.J & Caine, D. (1993) Physical and performance characteristics of injured and injury-free female gymnasts. *Journal of Human Movement Studies* **25**, 69–83.

Lowry, C.B. & LeVeau, B.F. (1982) A retrospective study of gymnastic injuries to competitors and noncompetitors in private clubs. *American Journal of Sports Medicine* **10**, 237–239.

Lueken, J., Stone, J. & Wallach, B.A. (1993) Olympic training center report on men's gymnastics injuries. *Gymnastics Safety Update* **8**, 4–5.

Lundin, O., Hellstrom, M., Nilsson, I. & Sward, L. (2001). Back pain and radiological changes in the thoraco-lumbar spine of athletes: a long-term follow-up. *Scandinavian Journal of Medicine and Science in Sports* **11**,103–109.

Mackie, S.J. & Taunton, J.E. (1994) Injuries in female gymnasts: trends suggest prevention tactics. *Physician and Sportsmedicine* **22**, 40–45.

Maffulli, N., Chan, D. & Aldridge, M.J. (1992) Derangement of the articular surfaces of the elbow in young gymnasts. *Journal of Pediatric Orthopaedics* **12**, 344–350.

Marshall, S.W., Covassin, T., Dick, R., Nassar, L.G. & Agel, J (2007) Descriptive epidemiology of collegiate women's gymnastics injuries: National Collegiate Athletic Association Injury Surveillance System, 1988–1989 through 203-2004. *Journal of Athletic Training* **42**, 234–240.

McGuine, T.A. & Keene, S. (2006) The effect of a balance training program on the risk of ankle sprains in high school athletes. *American Journal of Sports Medicine* **34**, 1103–1111.

McLain, L.G. & Reynolds, S. (1989) Sports injuries in a high school. *Pediatrics* **84**, 446–450.

Micheli, L.J. (1983) Overuse injuries in childrenís sports: the growth factor. *Orthopedic Clinics of North America* **14**, 337–360.

Mickel, T.J., Bottoni, C.R., Tsuji G., Chang, K., Baum, L. & Tokushige, K.A. (2006) Prophylactic bracing versus taping for the prevention of ankle sprains in high school athletes: a prospective, randomized trial. *Journal of Foot and Ankle Surgery* **45**, 360–365.

Mirca, M., Eleonora, S., Edy, B., Marina, P. & Marco, M. (2008) Pain syndromes in competitive elite level female artistic gymnasts. Role of specific preventive-compensative activity. *International Journal of Anatomy and Embryology* **113**, 1–8.

National Center for Catastrophic Sports Injury Research. (2007) *National Centre for Catastrophic Sports Injury Research—Twenty-fifth Annual Report: Fall of 1982—Spring of 2007*. URL http://www.unc.edu/depts/nccsi/AllSports.htm [accessed on August 14, 2008]

National Collegiate Athletic Association (1994) *National Collegiate Athletic Association 1993-94 Report: Men's and Women's Gymnastics Injury Surveillance System Report*, NCAA Kansas.

Olsen, O.E., Myklebust, G., Engebretsen, L., Holme, I. & Bahr, R. (2005) Exercises to prevent lower limb injuries in youth sports: cluster randomized controlled trial. *British Medical Journal* **330**, 449.

Petrie, T.A. (1992) Psychosocial antecedents of athletic injury: the effects of life stress and social support on female collegiate gymnasts. *Behavioral Medicine* **18**, 127–138.

Pettrone, F.A. & Ricciardelli, E. (1987) Gymnastic injuries: the Virginia experience 1982-83. *American Journal of Sports Medicine* **15**, 59–62.

Ryan, J. (1995) *Pretty girls in little boxes: The making and braking of elite gymnasts and figure skaters*. Doubleday, New York.

Sands, W.A., Shultz, B.B. & Newman, A.P. (1993) Women's gymnastics injuries: a 5-year study. *American Journal of Sports Medicine* **21**, 271–276.

Schmitt, H. & Gerner, J.H. (2001) Paralysis from sport and diving accidents. *Clinical Journal of Sports Medicine* **11**, 17–22.

Singh, S., Smith, G.A., Fields, S.K. & McKenzie, L.B. (2008) Gymnastics-related injuries to children treated in emergency departments in the United States, 1990-2005. *Pediatrics* **121**, e954–e960.

Singer, K.M. & Roy, S.P. (1984) Osteochondrosis of the humeral capitulum. *American Journal of Sports Medicine* **12**, 351–360.

Steele, V.A. & White, J.A. (1983) Injury amongst female gymnasts. *Proceedings of the Society of Sports Sciences: Sport and Science Conference*. School of Physical Education and Recreation, Liverpool.

Tsai, L. & Wredmark, T. (1993) Spinal posture, sagittal mobility, and subjective rating of back problems in former female elite gymnasts. *Spine* **18**, 872–875.

Vergouwen, P. (1986) Epidemiologie van blessures bij topturnsters. *Geneeskunde en Sport* **18**, 27–33.

Wadley, G.H. & Albright, J.P. (1993) Womenís intercollegiate gymnastics: injury patterns and “permanent” medical disability. *American Journal of Sports Medicine* **21**, 314–320.
Wedderkopp, M., Kaltoft, M., Holm, R. & Froberg, K. (2003) Comparison of two intervention programmes in young female players in European handball—with and without ankle disc. *Scandinavian Journal of Medicine and Science in Sports* **13**, 371–375.
Weiker. G.G. (1985) Injuries in club gymnastics. *Physician and Sportsmedicine* **13**, 63–66.

Chapter 13

Judo

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Introduction

Judo ("the gentle way") was initially derived from various styles of traditional Japanese jujitsu by Jigoro Kano, who opened the first dojo (training hall) for Kodokan judo in 1882. Although judo was to be a demonstration sport in the 1940 Tokyo Games (Amateur Athletic Foundation of Los Angeles 2005), it was not actually included in the Olympic program until 1964 (male-only events); then it was dropped for the 1968 Olympic Games and reinstated for the 1972 Olympiad, and it has remained on the Olympic program ever since. Events for women were introduced in the 1992 Games in Barcelona.

Judo is an extremely physically demanding combat sport consisting of techniques done from a standing position (tachiwaza), principally throws (nagewaza), or on the ground (newaza), such as grappling (katamewaza), arm-locks (kansetsuwaza), and choking techniques (shimewaza), and it has a high potential for injury. The purpose of this chapter is to examine the extant literature on judo-related injury. Overall, a paucity of well-designed, data-driven studies was evident.

Who Is Affected by Injury?

A comparison of studies reporting injury rates in shown in Table 13.1. The wide range (25.2–148) of the overall rate per 1,000 athlete exposures (AE) can be attributed to the variety of definitions used for a reportable injury (e.g., "any request for medical assistance"; "injury resulting in withdrawal from competition"), and the short duration (e.g., one competition) and the small sample sizes of many of the studies. Research that presents time-loss injury data is more cohesive, with rates ranging from ~4 to 10 per 1,000 AE. Frey et al. (2004) have completed the largest and most comprehensive study to date, with a 9-year study involving more than 150,000 male and female participants, from 11 years old to ⩾21 years old, competing at local through international level. Their findings indicated a rate of 44 per 1,000 AE for "any request for medical assistance" and a time-loss injury rate of 5.7 per 1,000 AE.

Various researchers have reported the number or percentage of judo-related injuries in comparison to other sports in an array of settings. For example, Kujala et al. (1995) used national sports injury insurance data to compare injury rates for six sports (soccer, ice hockey, volleyball, basketball, judo, karate) in Finland over a 5-year period and found that judo had the second highest injury rate (after karate). Similarly, Parkkari et al. (2004) completed a large community-based study of randomly recruited adults who played sports in Finland. Judo (n = 11) had the second fewest number of participants (after wrestling) but the second highest self-reported injury rate (after squash) of 31 sports: 16.3 (95% confidence interval [CI], 9.8–27.0) per 1,000 hours of participation. Velin et al. (1994) found

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Table 13.1 Comparison of judo injury rates.

Study	Design of Study	Data-Collection Method	Data Source (Duration of Study)	Location	No. of Participants	No. of Injuries	Injury Rate		
							Overall per 1,000 AE[a]	Time Loss per 1,000 AE[b]	Other
Nakata & Shirata (1943)	NA	DM	Osaka Police Department (1938–1942)	Japan	Men = 7,520	1672	–	–	22.2[a,c]
Sterkowicz (1981)	P	DM (NA)	6th Student World Championships (1980)	Poland	NA	57	81.4	8.6	–
Barrault et al. (1983)	P	DM (NA)	154 competitions (1980–1982/3?)	France	Male = 16,496 Female = 1,099	3,941 350	122.6 130.6	9.8 8.2	1.9[b,c] 2.0[b,c]
Rabenseifner (1984)	R	Q	Regional competitors (1 yr)	Germany	Men = 100	542	–	–	5.42[a,c]
Perren & Biener (1985)	R	Q	NA (10 yr)	Germany	Male = 199 Female = 43	285 49	– –	– –	15.0[a,d] 17.0[a,d]
Sturbois et al. (1987)	NA	RR	Physical Education Institute (1978–1984)	Belgium	NA	33	–	–	1.1[a,e]
Dah & Djessou (1989)	P	DM	9 competitions (1986–1987)	Ivory Coast	n = 120	87	115.0	4.0	2.5[b,c]
Kujala et al. (1995)	R	RR	National Insurance Competition & Training (1987–1991)	Finland	Male/ female = NA	1163	–	–	117[a,f]
Cunningham & Cunningham (1996)	P	DM	Australian University Games (1994)	Australia	n = 62	16	–	–	25.8[a,c]

Pieter & De Crée (1997)	P	DM	1 competition (1996)	United Kingdom	Boys = 111	25	77.2	–	22.5[a,c]
					Girls = 60	17	104.9	–	28.3[a,c]
					Men = 29	4	51.3	–	13.8[a,c]
					Women = 8	2	125.0	–	25.0[a,c]
Ganschow (1998)	R	Q	800 judoka (3 yr)	Germany	n = 800	1907	–	–	238.0[a,c]
Raschka et al. (1999)	R	RR	State Insurance Company (1981–1995)	Germany	NA	44	–	–	0.21[a,g]
James & Pieter (1999)	P	DM	1 competition (1996)	United Kingdom	Boys = 417	54	39.8	–	13.0[a,c]
					Girls = 270	45	52.1	–	16.7[a,c]
Pieter et al. (2001)	P	DM	Asian Championships (1997)	Phillippines	Men = 100	7	25.2	3.6	7.0[a,c]
					Women = 84	9	41.3	9.2	10.7[a,c]
Phillips et al. (2001)	P	DM	7th All Africa Games (1999)	South Africa	n = 210	62	148.0	–	29.5[a,c]
James & Pieter (2003)	P	DM	1 competition	United Kingdom	Men = 70	10	48.5	4.9	14.3[a,c]
					Women = 46	5	34.3	13.7	10.9[a,c]
Frey et al. (2004)	P	DM	French Judo Federation (9 yr)	France	n = 150, 007	17,618	44.0	5.7	1.5[b,c]
Atlas et al. (2007)	P	DM	University Team (2006)	Philippines	n = 14	14	–	–	100[a,c]
Green et al. (2007)	P	DM/Q	3 competitions (2005)	United Kingdom	Men = 284	40	41.3	10.3	14.1[a,c]
					Women = 108	13	40.9	18.9	12.0[a,c]

NA = information is not provided in the cited study; P = prospective; R = retrospective; DM = direct monitor; Q = questionnaire; RR = record review; AE = athlete exposures.

[a] Any injury for which medical assistance was sought

[b] Any injury which resulted in withdrawal from competition and/or inability to practice after the competition

[c] Per 100 participants.

[d] Per 100 participants/yr.

[e] Per 1,000 hr of participation.

[f] Per 1,000 person-years.

[g] Per 1,000 insured persons.

that judo ranked 11th of 25 sports represented in a 1-year study of emergency-department treatment of children in Nice, France, and accounted for 2.9% of all sports-related injuries treated. Cunningham and Cunningham (1996) reported that judo ranked seventh in the percentage of athletes injured of 19 sports at the 1994 Australian University Games (25.8% of judo athletes required some medical assistance).

Where Does Injury Occur?

Anatomical Location

The percent distribution of anatomical location of injuries is presented in Table 13.2. Overall, it appears that the upper extremities (mean, 39.3%; range, 21.3–62.9%), specifically the shoulder (mean, 15.2%; range, 4.6–37.1%), are injured most frequently, with the knee (mean, 14.7%; range, 4.3–27.8%) typically the most frequently injured location in the lower extremities.

However, given the costs and complications associated with knee injuries, a number of researchers have specifically examined this area. de Loës et al. (2000), in a 7-year study in Switzerland, calculated an incidence of knee injuries in 14-to-20-year-old male judoka of 0.2 (95% CI, 0.06–0.33) per 10,000 hours of participation and 0.19 (95% CI, 0.05–0.32) for female judoka. Majewski et al. (2006) completed a 10-year study of knee injuries in patients at an orthopedic clinic in Switzerland and found a rate of 2.7 per 1,000 participants per 10 years for judoka. Medial collateral ligament and anterior cruciate ligament (ACL) damage, with approximately equal distribution, comprised 83% of all knee trauma in this population. Busnel et al. (2006) noted an ACL rupture rate of 12.4 per 100 athletes per 6 years, whereas Mountcastle et al. (2007) found an ACL injury rate of 0.17 per 1,000 AE for men ($n = 5$) and 0.22 per 1,000 AE for women ($n = 1$).

Sterkowicz (1980) studied head injuries in regional, national, and international competitions in Poland (1,920 bouts) and reported a rate of 2.9 per 1,000 AE for head injuries requiring medical attention, and 1.3 per 1,000 AE for time-loss head injuries.

Environmental Location

Few studies have examined the relative distribution of judo injuries sustained in practice versus competition. However, the majority of those that have indicated that more injuries occur during practice. For example, although Atlas et al. (2007) reported that 57% of injuries were from competition in a group of 14 Philippine university judoka, and in a recall survey of 181 competitive judoka, Ransom & Ransom (1989) found that 55.9% of injuries were sustained in practice and 44.1% in competition. Kujala et al. (1995) noted that 70% of injuries occurred in practice and 30% in competition. Ganschow (1998) conducted a retrospective survey of 800 German judoka and identified 45.3% of injuries in practice, 30.2% in competition, 15% in warm-up, and 9.5% in technical training. Barsottini et al. (2006) completed a 1-year study of city clubs (São José dos Campos) and regional competitions in Brazil and reported that 71% of injuries occurred in practice with 29% in competition. Finally, Souza et al. (2006) also used a 1-year recall survey but found slightly fewer (43.6%) injuries in practice than competition (49.1%), with 7.3% in conditioning or not specified. Busnel et al. (2006) reported that 58.8% of ACL ruptures in their study occurred in competition versus 41.2% in practice.

When Does Injury Occur?

Injury Onset

All of the available injury literature for judo has focused on acute injuries. To date, no studies have examined the frequency or distribution of acute versus chronic injuries.

Chronometry

No studies have been located that examined the relationship between periods in a competitive season or time within a competition and injury.

What Is the Outcome?

Injury Type

The percent distribution of injury types is presented in Table 13.3. Overall, sprains (mean, 30.7%;

range, 10.0–56.6%) and contusions (mean, 23.8%; range, 4.6–56.8%) are the most common types of injury, indicating that most judo injuries are not serious. For example, in Frey et al. (2004), the most comprehensive study to date, 52.1% of time-loss injuries were sprains. However, in several studies, fractures, and dislocations are prominent.

Time Loss

Few studies examined the severity of judo injuries as reflected by time loss from participation. Overall, it appears the risk is low. Barrault et al. (1983) noted that although 31.4% of withdrawals from competition were sent to the hospital, this represented only 0.6% of all competitors. Parkkari et al. (2004) reported 60% of self-reported injuries (n = 12) did not result in any time loss and only 5% (n = 1) resulted in missing work or activity for at least 1 day. James and Pieter (2003) estimated time loss of ⩾21 days for a male competitor with a shoulder dislocation but ⩽7 days for two female competitors with elbow sprain. In a larger sample, Green et al. (2007) documented a mean of 21 days for 10 time-loss injuries in male judoka (not including a fractured clavicle) and a mean of 29 days for 6 time-loss injuries in female judoka (not including a medial collateral ligament rupture).

Clinical Outcome

Because of its physically demanding, high-impact nature (Figure 13.1), fatal and catastrophic injuries, in addition to a wide variety of other injuries with clinically important outcomes, have been reported in judo.

Fatal and Catastrophic Injuries

In one of the earliest available studies on fatalities in judo, Koiwai (1981) surveyed member nations of the International Judo Federation and found 19 deaths (from 20 official responses plus personal communication data) prior to 1981. However, Koiwai argued that only 10 could be specifically attributed to judo (the others were due to preexisting cardiac or other pathologies). Of the judo-attributable deaths, four were due to cerebral hemorrhage after being thrown, four to cervical fracture/dislocation after being thrown, one to soft-tissue neck injury, and one myocardial rupture. Hoshi & Inaba (2002) conducted a 13-year retrospective study of sports-related deaths in Japanese schoolchildren and reported 51 trauma-associated judo deaths and 7 heat-related judo deaths.

Katoh et al. (1996) conducted a 3-year (1990–1992) nationwide survey of sports-related spinal-cord injuries in Japan and found that judoka (n = 26) accounted for 4.9% of the total, although there was no bony involvement in 69.2% of judoka with spinal-cord injuries. Lannuzel et al. (1994) reported on an 11-year-old boy with ischemic stroke caused by dissection of the left vertebral artery following cervical trauma in judo practice. Delattre et al. (2005) noted partial left-sided nerve deficits following a cervical facet fracture in competition.

Closed head injuries have also been reported. de Vera Reyes (1970) detailed a case series (n = 3) of subdural hematoma from judo practice in which all recovered. However, in the Nishimura et al. (1988) case series of subdural hematoma (n = 4), only one recovered. Of the remaining three, one died and two were left in a permanent vegetative state. Hirakawa et al. (1971) studied sports-related head injuries and noted that subdural hematoma (n = 4) was found only in judoka.

Finally, Kujala et al. (1995) reported that 0.17% of judo injuries (two cases) in their study resulted in ⩾5% permanent disability.

Shimewaza-Related

Owens & Ghadiali (1991) reported a case of an experienced judoka with signs of anoxic brain damage and suggested that frequent shimewaza was the cause. However, Rodriguez et al. (1991, 1998) studied both the acute and chronic effects of shimewaza through electroencephalogram and regional cerebral blood flow studies in 10 competitive Italian judoka and concluded that there is no evidence to indicate a risk to central nervous system function from shimewaza.

Musculoskeletal Injuries

Kurosawa et al. (1996) reported on two cases of complete hamstring rupture (one each from uchimata

Table 13.2 Percent comparison of injury location in judoka.

Location	Nakata & Shirata (1943) (n = 1672)	Sasa (1958) (n = 1598)	Koiwai (1965) (n = 70)	Sterkowicz (1980) (n = 57)	Sturbois et al. (1980) (n = 593)	Horiyasu et al. (1982) (n = 115)	Barrault et al. (1983) (n = 1,790)	Rabenseifner (1984) (n = 542)	Perren & Biener (1985) (n = 334)
Head and neck	**6.6**	**5.4**	**10**	**19.3**	—	**4.3**	**22.2**	**0.7**	**8.7**
Head/ skull	1.4	—	5.7	—	—	—	9.2	0.7	—
Neck	1.9	—	4.3	—	—	4.3	4.2	—	—
Face	0.7	0.6	—	—	—	—	—	—	—
Eye	—	—	—	—	—	—	—	—	—
Ear	1.2	—	—	—	—	—	—	—	—
Mouth/ teeth	—	4.8	—	—	—	—	—	—	—
Nose	1.4	—	—	—	—	—	8.8	—	—
Trunk and back	**25.9**	**5.5**	**1.4**	**10.5**	—	**11.4**	**8.4**	**8.9**	**31.4**
Upper extremity	**32.2**	**25.9**	**62.9**	**31.6**	**52.8**	**33.0**	**38.4**	**39.7**	**21.3**
Shoulder	20.1	15.1	37.1	7.0	28.9	12.2	14.5	7.6	—
Arm	0.6	0.2	2.9	—	3.2	—	—	—	—
Elbow	6.0	5.8	12.9	19.3	7.4	12.1	13.5	2.2	—
Forearm	0.9	0.4	2.9	—	4.7	—	—	—	—
Wrist	1.4	—	—	—	1.8	6.1	1.8	14.4	—
Hand	0.9	2.6	2.9	5.3	1.8	—	8.6	—	—
Fingers	2.3	1.8	4.2	—	5.0	2.6	—	15.5	—
Lower extremity	**35.3**	**52.3**	**24.3**	**38.6**	**47.2**	**48.7**	**27.8**	**50.7**	**38.6**
Pelvis/ hips	—	2.0	—	1.8	—	—-	2.3	—	—
Thigh	2.2	0.5	—	—	1.2	—	(inc. in hip)	—	—
Knee	9.4	21.8	4.3	14.0	18.5	27.8	9.2	15.5	—
Leg	7.5	6.1	5.7	7.0	2.0	—	0.9	20.1	—
Ankle	6.9	19.9	2.9	7.0	14.9	17.4	6.4	10.3	—
Foot/toes	9.3	2.0	11.4	8.8	10.9	3.5	9.0	4.8	—
Other/ unreported	—	**10.9**	**1.4**	—	—	**2.6**	**3.2**	—	—

Dah & Djessou (1989) (n = 35)	Kujala et al. (1995) (n = 1163)	Carazzato et al. (1996) (n = 721)	Pieter & De Crée (1997) (n = 48)	Ransom & Ransom (1989) (n = 495)	Ganschow (1998) (n = 1907)	James & Pieter (1999) (n = 99)	Raschka et al. (1999) (n = 44)	Phillips et al. (2001) (n = 62)
14.3	**9.9**	**16.7**	**6.3**	**12.4**	**7.1**	**34.3**	**27.3**	**3.2**
—	6.3	—	2.1	2.2	1.2	11.2	6.8	3.2
8.6	(inc. in head)	—	4.2	—	—	2.0	—	—
—	—	—	—	—	—	3.0	—	—
5.7	0.9	—	—	0.8	5.9	—	2.3	—
—	—	—	—	2.4	(inc. in eye)	2.0	2.3	—
—	2.7	—	—	3.0	—	6.0	13.6	—
—	—	—	—	4.0	(inc. in eye)	10.1	2.3	—
8.5	**12.1**	**12.5**	**27.1**	**5.7**	**4.4**	**8.1**	**2.3**	**14.5**
42.9	**35.6**	**36.3**	**31.2**	**46.1**	**40.3**	**37.4**	**27.3**	**51.6**
17.1	20.0	—	10.3	20.6	16.9	10.1	4.6	—
—	(inc. in shoulder)	—	—	1.0	—	1.0	2.3	—
2.9	7.7	—	8.3	7.9	5.3	10.1	11.3	—
14.3	(inc. in elbow)	—	6.3	—	—	1.0	—	—
2.9	3.4	—	2.1	6.1	—	4.0	2.3	—
—	(inc. in wrist)	—	2.1	10.5	18.1	1.0	—	—
5.7	4.5	—	2.1	—	(inc. in hand)	10.1	6.8	—
34.3	**39.3**	**34.5**	**31.2**	**35.8**	**32.0**	**20.2**	**38.5**	**30.6**
—	0.7	—	2.1	—	—	—	—	—
2.9	1.9	—	2.1	1.6	—	2.0	—	—
5.7	20.2	—	20.7	8.9	13.7	9.1	13.6	—
5.7	2.0	—	—	—	—	—	2.3	—
2.9	8.3	—	4.2	7.3	9.3	5.1	15.8	—
17.1	6.2	—	2.1	18.0	9.0	4.0	6.8	—
—	**3.0**	—	**4.2**	—	**16.2**	—	**4.6**	—

(*continued*)

Table 13.2 (*continued*)

Location	Pieter et al. (2001) (n = 16)	James & Pieter (2003) (n = 15)	Frey et al. (2004) (n = 1749)	Barsottini et al. (2006) (n = 78)	Souza et al. (2006) (n = 110)	Green et al. (2007) (n = 53)	Yard et al. (2007) (n = 451)[a]
Head and neck	**18.9**	**40.0**	—	**1.0**	**0.9**	**18.9**	**23.4**
Head/skull	6.3	—	—	—	0.9	—	6.6
Neck	—	—	—	—	—	3.8	9.7
Face	—	6.7	—	—	—	7.5	7.1
Eye	—	6.7	—	—	—	—	—
Ear	—	6.7	—	—	—	—	—
Mouth/teeth	6.3	13.2	—	—	—	3.8	—
Nose	6.3	6.7	—	1.0	—	3.8	—
Trunk and back	**12.1**	—	**10.7**	**9.0**	**5.5**	**9.4**	**6.9**
Upper extremity	**43.7**	**33.4**	**50.1**	**37.0**	**45.5**	**41.5**	**45.3**
Shoulder	18.7	6.7	—	19.0	21.8	11.3	19.1
Arm	—	—	—	1.0	1.8	—	(inc. in shoulder)
Elbow	—	13.3	—	3.0	(inc. in all arm)	9.4	14.9
Forearm	—	6.7	—	—	—	—	(inc. in elbow)
Wrist	18.7	—	—	4.0	—	—	11.3
Hand	6.3	—	—	—	4.6	—	(inc. in wrist)
Fingers	—	6.7	—	10.0	17.3	20.8	—
Lower extremity	**31.2**	**26.6**	**27.1**	**53.0**	**46.4**	**28.3**	**24.4**
Pelvis/hips	—	—	—	3.0	—	—	—
Thigh	—	6.7	—	—	5.5	—	8.4
Knee	12.5	6.7	—	23.0	26.4	13.3	(inc. in thigh)
Leg	—	6.7	—	1.0	0.9	—	16.0
Ankle	—	6.7	—	14.0	10.0	7.5	(inc. in leg)
Foot/toes	18.7	—	—	12.0	3.6	7.5	(inc. in leg)
Other/unreported	**6.3**	—	**12.1**	**1.0**	**1.8**	**1.9**	**0.0**

[a] Annual estimate from National Electronic Injury Surveillance System database.
Values in bold print are the percent totals for each body region.

and tai otoshi) and recommended surgical repair in such incidents because one patient treated conservatively still had a 20% to 40% deficiency on isokinetic strength testing as compared with the contralateral side 7 years after the injury. Although magnetic resonance imaging showed nonunion of the hamstring with the ischial tuberosity, the athlete remained active in competition.

Frey and Muller (1984) noted Heberden nodes in 30% (9 of 30) members of the Swiss national judo team who were classified as having severe osteoarthritis of the distal interphalangeal joints and most also had proximal interphalangeal joint involvement. Strasser et al. (1997) completed a 16-year longitudinal case study of eight judoka, all of whom had radiologic changes indicative of osteoarthritis of

Table 13.3 Percent comparison of injury types in judoka.

Study	No. of Participants	No. of Injuries	Abrasion	Concussion/ neurologic injury	Contusion	Luxations	Fracture	Laceration	Sprain	Strain	Other/ Unknown
Nakata & Shirata (1943)	7520	1672	—	0.6	**42.6**	5.2	13.5	—	38.0	—	0.1
Sasa (1958)	458	1598	—	—	13.5	14.3	10.1	—	**56.6**	—	5.9
Koiwai (1965)	?	70	—	5.7	5.7	**38.8**	30.0	—	10.0	—	10.0
Sturbois (1980)	?	593	—	—	11.9	7.0	30.4	—	**38.6**	1.5	10.6
Sterkowicz (1981)	?	57	7.0	—	**38.6**	5.3	7.0	—	22.8	7.0	12.3
Horiyasu et al. (1982)	52	115	—	—	—	21.7	19.2	—	**56.5**	—	2.6
Rabenseifner (1984)	100	542	—	0.7	**56.8**	—	1.5	—	40.4	—	0.6
Perren & Biener	Men: 199	285	—	2.0	14.0	12.0	**28.0**	—	24.0	3.0	17.0
(1985)	Women: 43	49	—	—	13.0	4.0	18.0	—	**35.0**	8.0	22.0
Dah & Djessou (1989)	120	30	—	—	**46.7**	23.3	6.7	—	10.0	10.0	3.3
Kujala et al. (1995)[a]	?	1163	—	—	23.1[b]	3.9	11.3	—	**59.8**[c]	—	1.9
Cunningham & Cunningham (1996)	62	16	25.0	—	25.0	12.5	—	—	**31.3**	6.2	—
Pieter & De Crée (1997)	208	48	8.3	2.1	**45.9**	2.1	—	4.2	12.5	8.3	16.6
James & Pieter (1999)	687	99	7.1	6.1	**23.2**	2.0	1.0	8.1	21.2	19.2	12.1
Raschka et al. (1999)[a]	?	44	—	6.8	4.6	15.9	11.4	6.8	**38.6**	—	15.9
Pieter et al. (2001)	184	16	25	—	6.3	6.3	12.5	6.3	12.5	12.5	**18.7**
Phillips et al. (2001)	210	62	—	—	8.0	12.9	(inc. in luxations)	—	**72.6**[c]	—	6.5
dos Santos et al. (2001)	42	42	—	—	19.0	28.6	—	—	**38.1**	14.3	—
James & Pieter (2003)	116	15	6.7	—	**26.6**	6.7	—	13.3	20.0	20.0	6.7
Frey et al. (2004)[d]	150,007	1977	—	—	—	14.8	17.9	—	**52.1**	—	15.2
Souza et al. (2006)[a]	93	110	—	—	15.5	18.2	2.7	2.7	**39.0**	14.5	7.4
Green et al. (2007)	392	53	—	—	**34.0**	—	1.9	17.0	17.0	22.6	7.5
Yard et al. (2007)	?	410	—	4.1	**25.4**[b]	1.5	27.6	8.0	24.1[c]	—	9.3

[a] Includes practice and competition.
[b] Includes wounds.
[c] Includes strains.
[d] Time-loss injuries only.

Figure 13.1 Well-timed attacks generate high-velocity throws and high-impact forces. © IOC/Yo NAGAYA.

the finger joints. Although symptoms were reported as mild, the "degenerative changes were progressive and more pronounced" in active judoka.

Other reported unique acute traumatic musculoskeletal injuries in judo include dislocation of the proximal tibiofibular joint (Cossa et al. 1968), nerve damage secondary to shoulder dislocation (Jerosch et al. 1990), distal radio-ulnar dislocation (Russo & Maffulli 1991) and knee dislocation with arterial damage (Witz et al. 2004).

Ukemi-Related

The significant impact associated with individual and accumulated nagewaza has raised a variety of concerns, including damage to the renal and auditory systems. Norton et al. (1967) conducted extensive urinalysis of 204 active male judo players (pretraining and posttraining) and determined that judo resulted in no significantly different values than for other sports (i.e., not a risk to the renal system). De Meersman and Wilkerson (1982) in a controlled biomechanical study of nine judoka found that hematuria depended principally on the "severity of the mechanical trauma" rather than on the exercise per se (i.e., ukemi) and concluded that the quality of the tatami/competition surface may reduce the risk of athletic pseudonephritis in judoka. Fujita et al. (1988) presented a case report of perirenal hematoma, possibly developed over 30 years of judo training, that required surgical removal.

Fati et al. (1980) studied the acoustic function of 15 experienced young adult judoka and found consistent hearing loss in the frequency of 6,000 to 8,000 Hz, which was possibly due to damage to the organ of Corti and the auditory ossicles from ukemi.

Dermatologic

Dermatologic infections related to close contact are common in wrestling, and various studies have noted the same issue in judo. For example, Poisson et al. (2005) detailed the outbreak of tinea corporis gladiatorum in 49 of 131 members of a French judo team. Hirose et al. (2005) found that 35% (11 of 31) of members of a Japanese university judo club were dermatophyte carriers for *Tinea tonsurans* and Suganami et al. (2006) reported a prevalence of 9.1% of *T. tonsurans* among 496 male and female middle-school judoka at a national tournament in Japan.

Dental

Dental injuries in judo are also reported in the literature (Legrand et al. 1980; Parzeller et al. 1999;

Beachy 2004). However, the incidence appears low. For example, in a 15-year study of high-school judoka, Beachy (2004) reported an incidence of 0.19 of 1,000 AE (95% CI, 0–3.6) and Legrand et al. (1980) noted that dental injuries were sustained by 0.05% of >800,000 participants in a 3-year study. However, 86% of these injuries were broken teeth.

Economic Cost

Few data are available on the economic costs associated with judo-related injuries. Carazzato et al. (1996) reported in a retrospective study of 129 high-level judoka in Brazil that only 5% of injuries required surgery. de Loës et al. (2000) found an average cost of judo-related knee injuries in young male judoka (14–20 years) of US$950 (US$90 per 1,000 hours of participation) and US$797 (US$60 per 1,000 hours) for female judoka.

What Are the Risk Factors?

Intrinsic Factors

Several intrinsic risk factors have been examined in the literature, including sex, age, skill level, and weight. Although conclusions should be viewed with caution given the methodologic limitations, including inadequate power, some general observations may be possible.

The role of sex as a risk factor is unclear. For example, Pieter & De Crée (1997) found women to have a significantly greater rate of injury than men (106.7 per 1,000 AE vs. 72.1 per 1,000; $P<0.01$) but James & Pieter (2003) reported men to be at greater risk (48.5 per 1,000 AE vs. 34.3 per 1,000; $P<0.001$). However, Barrault et al. (1983), in the second largest judo injury study conducted to date, found no significant difference in the rate of time-loss injury between men and women (9.8 vs. 8.2 per 1,000 AE), which was supported by the findings of Green et al. (2007). James and Pieter (1999) indicated girls to have a significantly higher rate than boys (52.1 per 1,000 AE vs. 39.8 per 1,000; $P = 0.047$) but whether this difference is related to sex, age, or interaction between the two or whether it would be supported by further research has not been determined.

In addition, in studies in other sports, being female has been associated with an increased risk of sustaining an ACL injury. However, data from judo studies have not supported this finding. For example, although Wang and Ao (2001), in a 9-year retrospective study of hospital patients in China, found 9 times as many ACL injuries in female judoka as in male judoka (18 vs. 2), Ao et al. (2000) reported no difference (although no rate data are provided). Similarly, although de Loës et al. (2000) noted an 80% higher risk for cruciate injuries in females, the difference was not statistically significant, nor was the incidence of overall knee injuries (rate ratio, 1.0). A prospective 6-year study of 151 adolescent elite judo players (107 male; 44 female) by Busnel et al. (2006) came to the same conclusion. Finally, in a 10-year study of cadets at the U.S. Military Academy at West Point, Mountcastle et al. (2007) found no significant difference in the rate of complete anterior cruciate ruptures between men and women (incidence rate ratio, 1.3; 95% CI, 0.15–11.13).

The importance of age as a risk factor is also uncertain, especially as it may interact with experience as a causal factor. Barrault et al. (1983) first presented data on the significant discrepancy between the time-loss rate (per 1,000 AE) between children (15.9) and other age categories (seniors, 9.7; juniors, 8.7; cadets, 9.0). However, Kujala et al. (1995) reported a significantly greater rate for those 20 to 34 years old than for other age groups (183.7 vs. 72.1 per 1,000 person-years). Sterkowicz (1997) used a 4-year study of national insurance data in Poland and reported judoka ≤17 years old to be at potentially greater risk for upper-extremity injury (especially clavicular fracture) than those ≥18 years of age.

Several studies have examined the role of experience/expertise and weight in injury risk. Barrault et al. (1983) found that regional (12.7) and local (10.3) competitions had almost double the rate of time-loss injuries (per 1,000 AE) as national competitions (6.2). However, dos Santos et al. (2001) conducted a 1-year study of 42 judoka (beginners—dan grades) and found no relationship between injury and judo experience/expertise. Similarly, Barsottini et al.

(2006) and Green et al. (2007) reported no difference in injury rates between dan and kyu grades.

Although Barsottini et al. (2006) and Green et al. (2007) found no differences in injury rates across weight categories, Green et al. did note that losing ⩾5% of body weight before competition was significantly associated with being injured ($P = 0.02$) and Okada et al. (2007) found weight a risk for lumbar radiologic abnormalities and nonspecific low back pain in a study of 82 elite collegiate Japanese judoka (lumbar radiologic abnormalities prevalence in lightweight judoka, 65.5% vs. ~ 90% for middleweights and heavyweights ($P<0.05$)). The prevalence of nonspecific low back pain with lumbar radiologic abnormalities in lightweights was 50%, in middleweights 100%, and in heavyweights 88.9% ($P<0.05$).

Extrinsic Factors

No research was located that reported analysis of extrinsic risk factors in judo.

What Are the Inciting Events?

It is clear that tachiwaza is the primary source of judo injuries (mean, 72.2%; range, 42.4–90%), with seoi nage (mean, 28.4%; range, 23–33.8%) and tai otoshi (mean, 19.5%; range, 16.9–22.0%) being particularly problematic (Koiwai 1965; Horiyasu et al. 1982; James & Pieter 1999, 2003; Pieter et al. 2001; Souza et al. 2006, Green et al. 2007). However, aspects of attacking (throwing) and defending (being thrown) appear to be the inciting event in approximately equal proportions (Sterkowicz 1981; Horiyasu et al. 1982; James & Pieter 1999, 2003; dos Santos et al. 2001; Pieter et al. 2001; Green et al. 2007).

Injury Prevention

Over the years, a number of regulations designed to prevent injury in judo have been implemented. For example, participant safety has been a major consideration in judo as reflected in rules specifically designed to prevent injury. More than 100 years ago, locks on small joints, such as the fingers, toes, wrists and ankles, were banned. With the development of international competition, articles defining prohibited acts (specific techniques considered unsafe) and identifying violation of rules against actions "that are dangerous to the opponent" as a basis for disqualification were codified and have been in place for more than 50 years (International Judo Federation 1955, 2003). However, the efficacy of these regulations has been based on face validity, and no studies have been published indicating the actual validity, efficacy, or success of these rules to prevent injury. Moreover, no data-based injury-prevention studies of any kind have been located in the judo literature.

Further Research

Despite the long history and physical nature of judo, relatively little well-designed injury research has been conducted. Indeed, the Kodokan-based Association for the Scientific Study on Judo has not published an injury study in its Bulletin for 50 years (Sasa 1958), and Norton et al. (1967) included a plea that their study be the impetus for more "rigorously conducted scientific investigations" in judo. Although substantially more research has been conducted since then on a wide variety of judo-related topics, adequate large-scale and long-term epidemiologic work is still lacking.

If any significant progress is to be made in understanding the determinants of injury in judo, researchers have to use appropriate epidemiologic methods, including prospective designs, unambiguous definitions of reportable injuries (overall and time loss) and denominator data (exposure information). Incorporating trained medical professionals with standardized recording systems to collect the data for analysis within a coordinated series of regional and national databases is essential. The work of the Medical Commission of the French Judo Federation (Barrault et al. 1983; Frey et al. 2004) is the most extensive and well-structured currently available and is a good model for other groups, particularly national governing bodies and the International Federation, to follow. Hopefully, a 10-year study by USA Judo Sports Medicine that has been reported (Nishime 2007) but not yet published will be a useful addition to the paucity in the literature.

In addition to clarifying the rate of injury associated with judo participation, further work is needed to understand the nature and extent of time-loss injuries and the economic costs associated with injury in judo, variation in injury rates within competitions and across seasons and competitive careers, the impact of chronic injury, and risk and protective factors such as age, level of competition, conditioning, rules modifications, previous injury, and prophylactic taping. For example, the often repeated but unsubstantiated claim that judo is the safest contact sport for preadolescents (≤13 years old) (Nishime 2007) should be addressed. Similarly, Yamamoto, Kigawa & Xu (1993) compared traditional judo taping of ankles with functional taping to determine the effect on ankle stability via radiographic talar tilt measures. The functional taping was shown to effectively reduce talar tilt both before and during practice more than traditional bandaging. However, no epidemiologic studies have been undertaken to determine risk reduction with this type of prophylactic taping.

Judo is a highly regarded, widely practiced sport throughout the world but with an apparently high inherent risk for injury. Research to date indicates that the perception of injury risk due to the dynamic physicality of judo may be greater than the actual risk, but additional epidemiologic studies are needed to substantiate these findings and to identify ways to reduce injury rates. The medical commissions of national federations and the International Judo Federation as well as the International Association of Judo Researchers need to act as the coordinators of large-scale research projects to provide this information.

References

Amateur Athletic Foundation of Los Angeles. (2005) The report of the Organizing Committee on its work for the XIIth Olympic Games of 1940 in Tokyo until the Relinquishment. URL http://www.la84foundation.org/6oic/OfficialReports/1940/OR1940.pdf [accessed on July 12, 2008]

Ao, Y., Yu, C., Tian, D., Hu, Y., Cui, G., Shi, H. & Ren, Y. (2000). Anterior cruciate ligament injury in female athletes. *Chinese Journal of Sports Medicine* **19**(4), 387–388.

Atlas, A., Dones, V., Lizarondo, L. & Mallillin, T. (2007) Injuries of University of Santo Tomas college teams during the University Athletics Association of the Philippines Season 69. *Philippines Journal of Allied Health Sciences* **2**, 26–31.

Barrault, D., Achou, B. & Sorel, R. (1983) Accidents et incidents survenus au cours des compétitions de judo (in French). *Symbioses* **15**(3), 144–152.

Barsottini, D., Guimarães, A.E. & de Morais, P.R. (2006) Relationship between techniques and injuries among judo practitioners. *Revista Brasileira de Medicina do Esporte* **12**(1), 48e–51e.

Beachy, G. (2004) Dental injuries in intermediate and high school athletes: a 15-year study at Punahou School. *Journal of Athletic Training* **39**(4), 310–315.

Busnel, F., Rochcongar, P., Andre, A.-M., Beillot, J. & Jan, J. (2006). Isokinetic muscle knee evaluations in top level judo athletes and the risk of ACL ruptures (in French). *Science & Sports* **21**, 148–153.

Carazzato, J., Cabrita, H. & Castropil, W. (1996) Repercussão no aparelho locomotor da prática do judô de alto nível (in Portuguese). *Revista Brasileira de Ortopedia* **31**(12), 957–968.

Cossa, J.F., Evrard, C. & Poilleux, F. (1968) [One of the inconveniences of judo: isolated dislocation of the superior peroneo-tibial articulation] (in French). *Revue de Chirurgie Orthopedique et Reparatrice de L'Appareil Moteur* **54**, 211–214.

Cunningham, C. & Cunningham, S. (1996) Injury surveillance at a National Multi-Sport event. *The Australian Journal of Science and Medicine in Sport* **28**(2), 50–56.

Dah, C. & Djessou, P. (1989) Accidents et incidents liés au judo et au karaté au cours d'une saison sportive (1986–1987) en Côte-d'Ivorie (in French). *Cinesiologie* **28**, 153–157.

Delattre, O., Lemmonne, F., Massicot, R. & Uzel, A. (2005) Fracture-luxation uni-articulaire C5-C6 lors d'une competiition de judo: l'uchi-mata en cause [Unilateral C5-C6 facet fracture dislocation caused by an uchi-mata (judo inner thigh throw)] (in French). *Journal de Traumatologie du Sport* **22**(1), 65–69.

de Loës, M., Dahlstedt, L.J. & Thomée, R. (2000) A 7-year study on risks and costs of knee injuries in male and female youth participants in 12 sports. *Scandinavian Journal of Medicine & Science in Sports* **10**(2), 90–97.

DeMeersman, R.E. & Wilkerson, J.E. (1982) Judo nephropathy: trauma versus non-trauma. *Journal of Trauma* **22**(2), 150–152.

de Vera Reyes, J.A. (1970) Tres casos de hematoma subdural cronico por practica de judo (in Spanish). *Actas Luso-Españolas de Neurologia y Psiquiatria* **29**(1), 53–56.

dos Santos, S.G., da Silva Duarte, M. deF. & Galli, M.L. (2001) Estudo de algumas variáveis físicas como fatores de influência nas lesões em judocas

(in Portuguese). *Revista Brasilieira de Cineantropometria & Desempenho Humano* **3**(1), 42–54.
Fati, S., Marciano, E. & Nasti, G. (1980) Osservazioni sulle lesioni dell'orecchio nella practica dello judo agnostico (in Italian). *Medicina dello Sport* **33**(4), 231–238.
Frey, A. & Muller, W. (1984) [Heberden arthroses in judo athletes] (in German). *Schweizerische Medizinische Wochenschrift* **114** (2), 40–47.
Frey, A., Rousseau, D., Vesselle, B., Hervouet des Forges, Y. & Egoumenides, M. (2004) Neuf saisons de surveillance médicale de compétitions de judo (in French).*Journal de Traumatologie du Sport* **21**(2), 100–109.
Fujita, S., Kusunoki, M., Yamamura, T. & Utsunomiya, J. (1988) Perirenal hematoma following judo training. *New York State Journal of Medicine* **88**(1), 33–34.
Ganschow, R. (1998) Sportverletzungen im judo: risikoprofil und ansätze für die präverntion [Sports injuires in judo: high risk profile and approaches to prevention] (in German). *Deutsche Zeitschrift für Sportmedizin* **49**(3), 76–81.
Green, C.M., Petrou, M.J., Fogerty-Hover, M.L. & Rolf, C.G. (2007) Injuries among judokas during competition. *Scandinavian Journal of Medicine and Science in Sports* **17**, 205–210.
Hirakawa, K., Hashizume, K., Fuchinoue, T. & Nakamura, N. (1971) Patterns of craniocerebral injuries caused by sports (in Japanese). *No Shinkei Gaisho* **3**, 579–586.
Hirose, N., Shiraki, Y., Himura, M. & Ogawa, H. (2005) [An investigation of Trichophyton tonsurans infection in university students participating in sports clubs] (in Japanese). *Nippon Ishikin Gakkai Zasshi* **46**(2), 119–123.
Horiyasu, T., Takeuchi, Y., Nakamura, R., Sato, Y. & Nishibayashi, Y. (1982) Injuries in judo players. Presented at the 15th Japanese Annual Meeting of Budo, October 2–3, 1982, Tochigi, Japan
Hoshi, A. & Inaba, Y. (2002) External causes of mortality during exercise in school, 1986-1998 (in Japanese). *Japanese Journal of Physical Fitness & Sports Medicine* **51**(1), 85–92.
International Judo Federation. (1955) Contest rules of the Kodokan judo. URL http://www.judoinfo.com/rules2.htm [accessed on May 15, 2008]
International Judo Federation. (2003) IJF referee rules. URL http://www.ijf.org [accessed on March 20, 2008]
James, G. & Pieter, W. (1999) Competition injuries in young judo athletes. Presented at the 1st International Judo Federation Conference, October 4–5, 1999, Birmingham, England, URL http://www.judoinfo.com/research11.htm [accessed on Xxxxx XX, 20XX]
James, G. & Pieter, W. (2003) Injury rates in adult elite judoka. *Biology of Sport* **20**(1), 25–32.
Jerosch, J., Castro, W. & Geske, B (1990) Damage of the long thoracic and dorsal scapular nerves after traumatic shoulder dislocation: case report and review of the literature. *Acta Orthopaedica Belgica* **56**(3–4), 625–627.
Katoh, S., Shingu, H., Ikata, T. & Iwatsubo, E. (1996) Sports-related spinal cord injury in Japan (from the nationwide spinal cord injury registry between 1990 and 1992). *Spinal Cord* **34**(7), 416–421.
Koiwai, E.K. (1965) Major accidents and injuries in judo. *Arizona Medicine: Journal of the Arizona Medical Association* **22**(12), 957–962.
Koiwai, E.K. (1968) How safe is choking (shime-waza) in judo? In: *AAU-USJF Official Judo Handbook* (Pohl, D., ed.), AAU-USA, New York.
Koiwai, E.K. (1981) Fatalities associated with judo. *Physician and Sportsmedicine* **9**(4), 61–66.
Kujala, U.M., Taimela, S., Antti-Poika, I., Orava, S., Tuominen, R. & Myllynen, P. (1995) Acute injuries in soccer, ice hockey, volleyball, basketball, judo and karate: analysis of national registry data. *British Medical Journal* **311**, 1465–1468.
Kurosawa, H., Nakashita., K., Nakashita, H., Sasaki, S. & Takeda, S. (1996) Complete avulsion of the hamstring tendons from the ischial tuberosity: a report of two cases sustained in judo. *British Journal of Sports Medicine* **30**(1), 72–74.
Lannuzel, A., Moulin, T., Amsallem, D., Galmiche, J. & Rumbach, L. (1994) Vertebral-artery dissection following a judo session: a case report. *Neuropediatrics* **25**, 106–108.
Legrand, M., Lemoine, J.-J., Wouters, F. & Lamendin, H. (1980) Traumatismes bucco-dentaires dans la pratique des sports martiaux Japonais (in French). *Médecine du Sport* **54**(S2), 18–23.
Majewski, M., Habelt, S. & Steinbrück, K. (2006) Epidemiology of athletic knee injuries: a 10-year study. *The Knee* **13**, 184–188.
Mountcastle, S.B., Posner, M., Kragh, J.F. & Taylor, D.C. (2007) Gender differences in anterior cruciate ligament injury vary with activity: epidemiology of anterior cruciate ligament injuries in a young, athletic population. *American Journal of Sports Medicine* **35**(10), 1635–1642.
Nakata, M. & Shirata, N. (1943) [Statistical observation on injuries from judo] (in Japanese). *Nippon Seikeigeka Gakkai Zasshi [Journal of the Japanese Orthopaedic Association]* **18**, 1146–1154.
Nishime, R.S. (2007) Martial arts sports medicine: current issues and competition event coverage. *Current Sports Medicine Reports* **6**, 162–169.
Nishimura, K., Fujii, K., Maeyama, R., Saiki, I., Sakata, S. & Kitamura, K. (1988) Acute subdural hematoma in judo practitioners—report of four cases. *Neurologia Medicao-Chirurgica* **28**(10), 991–3.
Norton, M.L., Safrin, M. & Cutler, P. (1967) Medical aspects of judo. *New York State Journal of Medicine* **67**(12), 1751–1752.
Okada, T., Nakazato, K., Iwai, K., Tanabe, M., Irie, K. & Nakajima, H. (2007) Body mass, nonspecific low back pain, and anatomical changes in the lumbar spine in judo athletes. *Journal of Orthopaedic & Sports Physical Therapy* **37**(11), 688–693.
Owens, R.G. & Ghadiali, E.J. (1991) Judo as a possible cause of anoxic brain damage: a case report. *Journal of Sports Medicine and Physical Fitness* **31**(4), 627–628.
Parkkari, J., Kannus, P., Natri, A., Lapinleimu, I., Palvanen, M., Heiskanen, M., Vuori, I. & Järvinen, M. (2004) Active living and injury risk. *International Journal of Sports Medicine* **25**, 209–216.
Parzeller, M., Raschka, C. & Banzer, W. (1999) [Dental injuries in combative sports: a comparison between judo, wrestling and karate] (in Polish). *Medicine Sportiva* **3**(2), 123–126.
Perren, A. & Biener, K. (1985) Judosportunfälle—epidemiologie und prävention [Judo accidents—epidemiology and prevention] (in German). *Deutsche Zeitschrift für Sportmedizin* **36**(10), 294, 296, 298, 300.
Phillips, J.S., Frantz, J.M., Amosun, S.L. & Weitz, W. (2001) Injury surveillance in taekwondo and judo during physiotherapy coverage of the Seventh All-Africa Games. *South African Journal of Physiotherapy* **57**(1), 32–34.
Pieter, W. & De Crée, C (1997) Competition injuries in young and

adult judo athletes. In: *Proceedings of The Second Annual Congress of the European College of Sport Science*, Copenhagen, Denmark. August 20–23, 1997.
Pieter, W., Talbot, C., Pinlac, V. & Bercades, L.T. (2001) Injuries at the Konica Asian Judo Championships. *Acta Kinesiologiae Universitatis Tartuensis* **6**, 102–111.
Poisson, D.M., Rousseau, D., Defo, D. & Esteve, E. (2005) Outbreak of tinea corporis gladiatorum, a fungal infection due to *Trichophyton tonsurans*, in a French high level judo team. EuroSurveillance 10(9), 187–190.
Rabenseifner, L. (1984) Sportverletzungen und sportschäden im judosport [Sports injuries and sports damage in judo] (in German). *Unfallheilkunde* **87**(12), 512–516.
Ransom, S.B. & Ransom, E.R. (1989) The epidemiology of judo injuries. *Journal of Osteopathic Sports Medicine* **3**(1), 12–14.
Raschka, C., Parzeller, M. & Banzer, W. (1999) 15jährige versicherungsstatistik zu inzidenzen und unfallhergangstypen von kampfsportverletzungen im Landessportbund Rheinland-Pfalz [15 years of actuarial statistics concerning insurance-related trauma incidences and accident types in the combat sports in the Rhineland-Palatinate sports association] (in German). *Sportverletzung Sportschaden* **13**, 17–21.
Rodriguez, G., Francione, S., Gardella, M., Marenco, S., Nobili, F., Novellone, G., Reggiani, E. & Rosadani, G. (1991) Judo and choking: EEG and regional cerebral blood flow findings.*Journal of Sports Medicine and Physical Fitness* **31**(4), 605–610.
Rodriguez, G., Vitali, P. & Nobili, F. (1998) Long-term effects of boxing and judo-choking techniques on brain function. *Italian Journal of Neurological Sciences* **19**, 367–372.
Russo, M. & Maffulli, N. (1991) Dorsal dislocation of the distal end of the ulna in a judo player. *Acta Orthopaedica Belgica* **57**(4), 442–446.
Sasa, T. (1958) Various forms of injury caused by judo. *Bulletin of the Association for the Scientific Study on Judo, Kodokan* **1**, 99–104.
Souza, M., Monteiro, H., Del Vecchio, F. & Gonçalves, A. (2006) Referring to judo's sports injuries in Sao Pãulo State Championship. *Science & Sports* **21**, 280–284.
Sterkowicz, S. (1980) W sprawie zapobiegania urazom glowy u judoków [On protection against head injuries in judo players] (in Polish). *Sport Wyczynowy* **18**(18–9), 62–65.
Sterkowicz, S. (1981) Wypadkowosc na VI Akademickich Mistrzostwach Swiata w judo (Wroclaw 1980) [Injury rate at the 6th Students World Championships in judo (Wroclaw 1980)] (in Polish). *Sport Wyczynowy* **19**(10), 48–52.
Sterkowicz, S. (1997) Body injuries in youth training in judo. URL http://www.judoinfo.com/research4.htm [accessed on November 11, 2007]
Strasser, P., Hauser, M., Hauselman, H.J., Michel, B.A., Frei, A. & Stucki, G. (1997) [Traumatic finger polyarthrosis in judo athletes: a follow-up study] (in German). *Zeitschrift fur Rheumatologie* **56**(6), 342–350.
Sturbois, X. (1980) Pathologie traumatique du licencié de judo en Belgique (in French). *Médecine du Sport* **54**(S2), 13–14.
Sturbois, X., Ramyead, R. & Noens, C. (1987) Incidence des lésions dues à l'enseignement du judo dans un institut d'éducation physique (in French). *Cinésiologie* **112**(March/April), 67–71.
Suganami, M., Hirose, N., Shiraki, Y., Hiruma, M. & Ikeda, S. (2006) [Trichophyton tonsurans infection among judo practitioners who attended the National Junior High School Judo Tournament in Japan (2005): incidence and therapeutic response] (in Japanese). *Nippon Ishikin Gakkai Zasshi* **47**(4), 319–24.
Velin, P., Four, R., Matta, T. & Dupont, D. (1994) Évaluation des traumatismes sportifs de l'enfant et de l'adolescent (in French). *Archives de Pédiatrie* **1**(2), 202–07.
Wang, J. & Ao, Y. (2001) Epidemiological study of anterior cruciate ligament injury (in Chinese). *Chinese Journal of Sports Medicine* **20**(4), 380–82.
Witz, M., Witz, S., Tobi, E., Shnaker, A. & Lehmann, J. (2004) Isolated complete popliteal artery rupture associated with knee dislocation. *Knee Surgery, Sports Traumatology, Arthroscopy* **12**, 3–6.
www.judoinfo.com/olympics.htm [accessed on May 12, 2008]
www.judoresearch.org [accessed on February 23, 2008]
Yamamoto, T., Kigawa, A. & Xu, T. (1993) Effectiveness of functional ankle taping for judo athletes: a comparison between judo bandaging and taping. *British Journal of Sports Medicine* **27**(2), 110–112.
Yard, E.E., Knox, C.L., Smith, G.A. & Comstock, R.D. (2007) Pediatric martial arts injuries presenting to Emergency Departments, United States 1990–2003. *Journal of Science and Medicine in Sport* **10**, 219–226.

Chapter 14

Modern Pentathlon

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Introduction

Modern pentathlon is a sports contest consisting of five events—shooting (4.5-mm air pistol), fencing (epee, one hit), swimming (200-m freestyle), riding (jumping course, with randomly chosen horse), and—until 2008—a final cross-country run (3000 m). At the beginning of 2009, the single components shooting and running have been joined together to a so-called "combined event", similar as in biathlon, and is performed either as a final cross-country run or on a track. Thus, athletes must have very different physical qualities from those of athletes in single component contests (Frohberger *et al*. 1987; Minder 1987; Parisi *et al*. 2001; Brodani & Krajcovic 2007).

The modern pentathlon became an Olympic discipline at the 1912 Olympic Games in Stockholm at the instigation of Pierre de Coubertin, but it was not an Olympic event for women until the 2000 Games in Sydney. Initially, modern pentathlon competitions were held over 5 days, with one event each day; however, since 1993, competitions have been conducted as 1-day-events (i.e., all five disciplines on a single day) at all international competitions (Kelm & Kirn 1997).

Because of the limited public profile of modern pentathlon, sports medicine research in this area is lacking (Schmitz 1985). Currently, only two studies (Schmitz 1985; Kelm et al. 2003) have denominator-based data on trauma associated with the modern pentathlon. However, the Schmitz (1985) data were collected before the introduction of the current 1-day competition format and may not accurately reflect contemporary conditions. Although the two studies use similar definitions for acute and chronic injuries (see the section "What Is the Outcome?"), Schmitz (1985) does not include sports-induced illness or diseases in her analysis. The consideration of these additional health problems related to multidiscipline events is important because of their high negative impact in training (Kelm et al. 2003).

Who Is Affected by Injury?

Neither Schmitz (1985) nor Kelm et al. (2003) document time-loss injuries, but they report overall injury rates based on any incidents requiring treatment by medical staff. Nonetheless, the incidence of pentathlon-related health problems appears to be quite low.

In her study of 219 pentathletes, Schmitz (1985) found the following rates of injury for each discipline per 10,000 hours of participation: 8.6 in riding, 5.6 in running, 1.4 in fencing, and 0.8 in swimming. No injuries were reported for shooting. Kelm et al. (2003) recorded 224 health incidents in 108 athletes over one competition year, resulting in a rate of 2.07 incidents per athlete per year. Acute injuries occurred at a rate of 0.5 per athlete per year.

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Table 14.1 Percentage distribution by anatomical location of reportable incidents (Kelm et al. 2003).

Location	Acute Injuries	Chronic Injuries	Illness	Others	Total
Head/neck	4%	1%	92%	3%	40%
Pelvis/lower extremity	39%	51%	8%	2%	37%
Shoulder/upper extremity	38%	58%	0%	4%	13%
Torso	11%	14%	50%	25%	10%

Where Does Injury Occur?

Anatomical Location

With respect to anatomical location, the head and neck region (40%) is the most frequently affected part of the body (principally because of upper respiratory tract infections), followed by the pelvis and lower extremities (37%), the shoulder girdle and upper extremities (13%), and the torso (10%) (Table 14.1). The majority of affected structures are the mucous membranes of the respiratory system, followed by muscles (n = 40), bones (n = 36), tendons (n = 32), and ligaments (n = 23) (Kelm et al. 2003). Schmitz (1985) reported a similar distribution.

Environmental Location

According to Kelm et al. (2003) the majority (84%) of reportable incidents happen during training, but the proportion of acute injuries was significantly higher ($P < 0.01$) in competition. As noted previously, Schmitz (1985) reported that riding had the highest rate of injuries of the five pentathlon events. Kelm et al. (2003) found that riding, fencing, and running accounted for 40%, 26%, and 18% of acute injuries but no exposure data are provided (Table 14.2).

When Does Injury Occur?

Injury Onset

Of the 224 reportable incidents in Kelm et al. (2003), the majority were illness (41%) or chronic injuries (33%), followed by acute injuries (23%). The remaining 3% could not be clearly assigned to a specific category.

Table 14.2 Percentage distribution of injury type by specific event (Kelm et al. 2003).

Events	Acute injuries	Chronic injuries	Illness	Others	Total
Running	18%	47%	32%	3%	36%
Fencing	26%	46%	23%	5%	23%
Swimming	6%	28%	61%	5%	19%
Riding	40%	13%	33%	14%	15%
Shooting	0%	42%	58%	0%	7%

Chronometry

With respect to the distribution of incidents throughout a season, more occurred preseason (60%) than in-season (40%). Nevertheless acute injuries (38%) occurred significantly more frequently ($P < 0.01$) in-season than preseason (18%) (Kelm et al. 2003).

What Is the Outcome?

Schmitz (1985) and Kelm et al. (2003) defined reportable incidents in the modern pentathlon as follows: (a) acute injury: acute traumatic dysfunction during sports due to a disproportion between physical strain and maximum stress (Krahl & Steinbrück 1980); (b) chronic injury: chronic dysfunction as direct result of mechanical (over)use due to sports, or chronic dysfunction resulting from incomplete healing after an acute sports injury (Groh & Groh 1975); (c) illness: physical impairment due to sports that cannot be ascribed to an acute or chronic injury (Kirn-Jünemann 1998); and (d) other: health impairment that cannot be clearly ascribed to one of the above-mentioned categories (Kirn-Jünemann 1998).

Table 14.3 Percentage distribution by type of reportable incidents (Kelm et al. 2003).

	Acute Injuries	Chronic Injuries	Illness	Others
Total	**23%**	**33%**	**41%**	**3%**
Contusions	26%			
Strains	23%			
Sprains	15%			
Ruptures	11%			
Fractures	10%			
Abrasions	6%			
Luxation	5%			
Others	4%			
Stress fractures		10%		
Tendinitis				
Fasciitis		72%		
Periostitis				
Existing sprains		4%		
Existing luxations		2%		
Others		12%		
Otitis				
Pharyngitis			91%	
Laryngitis				
Others			9%	

Figure 14.1 The final event, running, causes predominantly chronic injuries (47%).
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Injury Type

The majority of world-class athletes studied suffered from illness (41%) and chronic injuries (33%) (Table 14.3). Acute injuries (23%) were not frequent (Kelm et al. 2003). The majority of illnesses were otitis and pharyngitis, with principal chronic injuries being tendinditis and periostitis. Although the majority of acute injuries were contusions, strains, and sprains, there was a high proportion of stress fractures (chronic [overuse] injury) in the lower extremities (n = 7; 5 distal tibia, 2 metatarsal) in relation to a total of 13 fractures.

The distribution of incident categories by event are listed in Table 14.2. The majority of incidents were associated with running (36%), with chronic injuries accounting for 47% of running-related problems (Figure 14.1), as compared with 18% for acute injuries. Fencing injuries (23%), ranked second, were also predominantly chronic injuries (46%), whereas riding (15%) was dominated by acute injuries (40%). Shooting (7%) had few reportable incidents and no acute injuries (Kelm et al. 2003).

Time Loss

Kelm et al. (2003) reported that a majority (67%; 150/224) of reportable incidents led to cancellation of training or competition or both, with an average of 10 days of nonparticipation during the preseason. Approximately 16% (36/224) of time-loss events occurred during a competition but only 3 of these 224 events resulted in more than 1 week of nonparticipation (Kelm et al. 2003). Schmitz (1985) reported a case in her cohort that required cessation of all sports activities for 2.5 years, but no details are provided. However, the athlete returned to participation, and there have been no reports in which the pentathlon had to be given up after an injury (Schmitz 1985).

Clinical Outcome

Most reportable incidents in the modern pentathlon appear to be minor. However, serious injury can occur, particularly in riding. Kelm et al. (2003) documented a posterior cruciate ligament rupture and a scapula fracture, both sustained during riding, and Schmitz (1985) reported a complex femoral fracture with an arterial vascular injury, also sustained during riding.

Economic Cost

Because of the small number of athletes and injury incidents, the economic impact of modern pentathlon-related injuries is not significant for health insurance systems. Kelm et al. (2003) found no instances of inability to work caused by the modern pentathlon.

What Are the Risk Factors?

Intrinsic Factors

Sex

Although Kelm et al. (2003) noted no sex differences in the frequency of acute and chronic injuries, there was a significant ($P = 0.025$) difference with respect to the frequency of illness, which was more common in women than in men (average. 1.32 vs. 0.67 incidents per person per year). In addition, women were more likely to sustain ligament pathologies than men (13% vs. 3%; P = 0.002). However, men had more muscle-related injuries than women (21% vs. 10%; P = 0.013).

Age

Frequency of illness has been found to be negatively correlated with age, irrespective of sex (r = −0.28; P = 0.0034) (Kelm et al. 2003).

Extrinsic Factors

There are currently no studies that have examined the association between extrinsic factors and the risk of injury.

What Are the Inciting Events?

Little research is available on causative events in pentathlon injuries. However, 81% of acute injuries in riding are associated with falling from the horse (Kelm et al. 2003).

Injury Prevention

No intervention studies to address injuries in the modern pentathlon have been conducted.

Further Research

Currently, the research literature on the epidemiology of the modern pentathlon is very poor and consists of only limited retrospective data. Because all competitive modern pentathletes are registered with both the world association and national associations, physicians and coaches should be recruited to develop prospective surveillance systems of at least one contest year (but, preferably more) to examine the problem of injury in this multidiscipline event more precisely. This will require standardized definitions of both acute and chronic injuries, as well as of the sports-induced illness. In addition, research on preseason and in-season injuries and the risk associated with the participation of children and young adults is vital. Specifically, the impact of regular clinical examinations, especially of young athletes, in promoting the early treatment of acute injuries and reducing chronic problems of the locomotor system needs to be examined (Szekelly 1996). Equipment modification, especially footwear for running and fencing, and efficient training protocols must also be carefully examined in controlled research. Finally, prospective, comparative studies with athletes from specialized disciplines could finally shed light on pentathlon-specific acute and chronic injuries and injury patterns so that effective prevention programs can be developed to eliminate them.

References

Brodani, J. & Krajcovic, J. (2007) Struktura sportveho vykonu v modernom pät'boji muzov. *Telesna Vychova a Sport* **17**, 22–24.

Frohberger, U., Schmitz-Losem, J. & Rieden, H. (1987) Leistungssport Moderner Fünfkampf. Praktische *Sport-Traumatologie und Sportmedizin* **1**, 4–10.

Groh, H. & Groh, P. (1975) *Sportverletzungen und Sportschäden*. Luitpold-Werk, München.

Kelm, J. & Kirn, U. (1997) Zur Entwicklung des Modernen Fünfkampfes. *Sportorthopädie—Sporttraumatologie* **13**, 177–179.

Kelm, J., Ahlhelm, F., Pitsch, W., Kirn-Jünemann, U., Engel, C., Kohn, D. & Regitz T. (2003) Sports injuries, sports damages and diseases of world class athletes practicing modern pentathlon. *Sportverletzung—Sportschaden* **17**, 32–38.

Kirn-Jünemann U. (1998) Sportverletzungen, Sportschäden und Erkrankungen bei Modernen Fünfkämpfer(inne)n der Weltklasse. Dissertation. Universität des Saarlandes, Homburg/Saar.

Krahl, H. & Steinbrück, K. (1980) Traumatologie des Sports. Grundbegriffe und Analysen. *Orthopädische Praxis* **14**, 28.

Minder, P. (1987) Moderner Fünfkampf. *Sportinformation* **10**, 14–16.

Parisi, A., Masala, D., Cardelli, G. & Di Salvo, V. (2001) Il pentathlon moderno. *Medicina dello Sport* **54**, 243–246.

Schmitz I. (1985) Sportschäden und Sportverletzungen bei Modernen Fünfkämpfern. Dissertation. Rheinische Friedrich—Wilhelm Universität, Bonn.

Szekelly, G. (1996) A "Sydney 2000" programban reszt vevoe sportolok klnikai viszgalata. *Hungarian Review of Sports Medicine* **37**, 5–10.

Chapter 15

Rowing

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Introduction

Competitive rowing has a long and storied tradition dating back several hundred years, and the International Federation of Rowing Associations (FISA; founded in 1892) is the oldest sporting federation in the Olympic movement. There are two types of rowing: sculling (using two oars), and sweeping (using one oar as in Figure 15.1). In sculling, there are three boat classes: the single, double, and quadruple sculls. In sweep, there are also three classes: the pair, four (with or without coxswain), and eight (always with coxswain).

Numbers in collegiate rowing participation have increased steadily in recent years, with a large rise occurring because of the advent of Title IX in the United States. This regulation requires equal proportions of male and female athletes in collegiate sports, and women's rowing was one of the sports that profited from a need to balance out the numbers on male football teams.

The increase in participation is encouraging, as rowing confers several important health benefits, including lower rates of cardiovascular disease, diabetes, and obesity (Seiler 2004). Rowing also exerts a protective effect on bone mineral density in the spine, because of the load placed on the vertebrae during each stroke (Wolman et al. 1990). However, the demanding training regimen and repetitive nature of the movement can predispose the rower to various musculoskeletal injuries.

Figure 15.1 Sweep rowers use one oar each. Photo credit: Dr. Volker Nolte

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Although rowing ranks among the most aerobically strenuous of sports, life-threatening or permanent injury is extremely rare. Acute deaths occurring in the sport can usually be attributed to undiagnosed cardiomyopathy or abnormal cardiac function (McNally et al. 2005).

Because rowing is also a highly technical sport, errors in technique can easily lead to injury; as improperly supported forces approaching 1000 N are placed on the lumbar spine and supporting structures. Although many injuries stem from overuse and can be treated successfully with conservative treatment, there are a few injuries incurred from rowing that can be debilitating and unresponsive to conservative therapy. Preventive strategies can be difficult to implement, as the reason for onset of certain rowing injuries is still not fully understood.

Although several review articles on rowing injuries exist (Karlson 2000; McNally et al. 2005; Rumball et al. 2005), there has not yet been an extensive epidemiologic overview of the rowing injury literature. The purpose of this chapter is to comprehensively review the existing epidemiologic data on injuries as reported in the rowing injuries literature, and to recommend important areas for further research.

The vast majority of studies are descriptive and theoretical in nature, and case study reports abound. There are several methodologic limitations in the existing research, which include differences in subject characteristics (experience level, fitness level, age, and sex), instability of results due to short periods of data collection, low sample size, variability in injury definition, and bias due to retrospective questioning and analysis. There is also a large difference between rowing-specific injury and injury occurring to rowers (which may have resulted from other training, such as lifting weights or running), and this fact is not always reported. Furthermore, changes in equipment over the years have theoretically led to different injury patterns, severity, and risk. Rules of racing have changed; women's rowing was not introduced at the Olympic level until 1976, and lightweight rowing in 1996 (lightweight men's double and four, lightweight women's double).

With these factors in mind, there still continues to be a strong and consistent pattern to injury onset, cause, and prognosis within the sport of rowing, which is detailed herein.

Who Is Affected by Injury?

Rowing injury research typically focuses on the collegiate and elite rowing population. International competition begins at the junior level (<19), while most senior World Championship competitors are in their 20s and 30s. Masters rowing is a division for rowers not currently training at the World Championship level and who are ⩾27 years of age.

Overall Injury Rates

The vast majority of studies investigating rowing-specific injury do not report the rate of injury relative to time or athlete-exposures, making comparison difficult.

Weightman and Browne (1975) documented injury rates for 11 selected sports and reported an injury rate of 1.4 per 10,000 person-hours for rowing (the highest rate was 36.5 for football). However, it was unclear whether all of these injuries were rowing-induced. For example, two rowers suffered broken ankles, although there is no mechanism of onset stated and nowhere else in the literature is this type of injury reported. The authors concluded that rowing is "a very safe sport."

Hickey et al. (1997) conducted a retrospective analysis during a 10-year period (1985 through 1994) on the injuries of male and female rowers at the Australian Institute of Sport (AIS). During that time, 320 injuries were documented by 172 rowers.

An earlier retrospective survey also from the AIS by Reid et al. (1989) focused on 40 female rowers on AIS scholarships between 1985 and 1989. During that time, 25 of the 40 presented for rowing-related injuries, accounting for 61 rowing injuries in total.

More recently, a survey study of Irish rowers by Wilson et al. (2004) reported a history of injury by 66.5% of male and 69.6% of female rowers. In this study, 227 questionnaires were analyzed, representing 18.7% of the total rowing population of Ireland.

Sex Differences

There is evidence suggesting a sex difference in rowing injury rate and location. In an extensive report by Hickey et al. (1997), 84 females accounted for 204 injuries, while 88 males accounted for 116 injuries. Female rowers had an average of 1.58 injuries per scholarship-year, and male rowers had an average of 0.85.

Where Does Injury Occur?

An overall percentage comparison of injury location across studies is shown in Table 15.1. A review of the data in this table indicates that the spine was the most frequently injured region for rowers (range, 23.1–59.0%), followed by the chest area (range, 6.0–22.6%) and the forearm/wrist region (range, 2.3–15.5%). The region of the spine most frequently injured was the lumbar spine (range, 9.8–45.0%).

When Does Injury Occur?

Injury Onset

There is a lack of reporting on the number of acute and overuse injuries in the rowing literature to date. However, Hickey et al. (1997) demonstrated that injuries sustained by rowers are mostly overuse in nature. Of 320 injuries observed over a 10-year period, 92 were acute (29%), while 228 were overuse (71%). The ratio of acute to overuse injuries in female rowers was 1:2.58, and in male rowers was 1:2.31. Respondents to a 2004 survey of rowing injuries in Ireland described the majority of injury onset as "slow progression" during rowing (43.6%) or "sudden onset" during rowing (18.5%) (Wilson et al. 2004).

Chronometry

Time of Day

It has been postulated that there is a higher risk for back injury while practicing during an early-morning hour (Adams et al. 1987; Urban & McMullin 1988; Reid & McNair 2000), when disks are still imbibed with fluid and more prone to injury. However, there are no prospective data to confirm this theory.

Table 15.1 Percent comparison of overall injury location in club and elite rowing.

	Elite					Mixed	Club
	Hickey et al. (1997)	Hickey et al. (1997)	Reid et al. (1989)	Wajswelner et al. (1995)	Coburn & Wajswelner (1993)	Wilson et al. (2004)	Wajswelner et al. (1995)
Study Design	R	R	R	NS	NS	R	NS
No. of injuries	204 (female)	116 (male)	61 (female)	132	54	NS (227 surveys)	90
Head/Face	1	0.9	—	—	—	—	—
Spine							
Cervical	1	1.7	4.9	12.9	8	6	—
Thoracic	6.9	1.7	9.8	11.4	6	10.5	5.6
Lumbar	15.2	25	9.8	28	45	27	44.4
Shoulder/Upper Arm	5.4	5.2	4.9	9.8	9	5	—
Elbow	3.4	1.7	—	1.5	—	—	—
Forearm/wrist	14.7	15.5	15	2.3	—	8.5	10
Hand	4.9	8.6	4.9	1.5	—	—	—
Trunk/abdomen	1	0.9	11.4	—	—	—	—
Chest	22.6	6	21.3	6.1	11	5.8	20
Hip/pelvis/groin/buttock/thigh	6.9	10.3	6.6	9.1	9	—	—
Knee	9.3	12.9	9.8	4.5	6	9	6.7
Lower leg	0.5	1.7	—	—	6	—	—
Foot/ankle	6.4	6.9	—	6.1	—	—	—
Other	1	0.9	4.9 (disc)	8.3	—	8.4 (disc)	13.8

NS = not specified; P = prospective; R = retrospective.

Time of Season

Rates of injury are much higher during the transitional period between dry land and on-water training, as well as during heavy training periods that emphasize a large volume of work coupled with high intensity. Hickey et al. (1997) observed two peak times for injury presentation in both women and men in Australia: May–June (high volume) and the summer racing period of November–February (high intensity). July had the lowest reported frequency, but the authors postulated that it may be due to the fact that athletes were away competing in the northern hemisphere.

Data collected on the Canadian national team during the years 1991 through 1996 substantiate these findings, as the majority of rib stress fractures occurred during the high-volume months (December–February) and race preparation months (March–May) (R. Backus, Canadian team physician: unpublished observations).

What Is the Outcome?

Injury Type

No epidemiologic studies provide an overall description of injury types incurred during rowing. Instead, reports have focused on the frequency and severity of injury types believed to be common in rowing. These include injuries involving the low back, rib and chest, shoulder, forearm and wrist, and knee.

Back

The prevalence of injuries to the spine appears to be on the increase (Teitz et al. 2002). Although rowers who do not have back pain during collegiate years have a lower incidence of back pain than the general population (Roy et al. 1990; Hickey et al. 1997; Teitz et al. 2003; McNally et al. 2005), those who experience back pain causing ⩾1 weeks of lost practice will likely have a recurrence (Teitz et al. 2003).

Rib and Chest

There are reports of injuries to the chest, including costochondritis, intercostal muscle strain, and costovertebral joint subluxation (Thomas 1988; Rumball et al. 2005); however, rib stress fractures account for the vast majority of injuries to this region. Typically, the posterolateral angle of ribs 5 to 9 is the area most frequently affected (Karlson 2000).

The rate of stress fractures of the ribs is reported to be between 6.1 and 22.6% (Hickey et al. 1997; Warden et al. 2002), with a higher reported proportion in women. Of note, is the finding that injuries to the chest area comprise 26% of overuse injuries in women but only 9% in men (Hickey et al. 1997), supporting other reports that female rowers experience a higher rate of stress fractures of the ribs (Wajswelner 1995; Karlson 2000). However, other data suggest no sex difference (Hannafin 2000).

Furthermore, data collected during the years 1991 through1996 on the Canadian National Rowing team indicate no difference in the proportion of stress fractures of the ribs between lightweight and heavyweight rowers, scullers and sweepers, or men and women (Table 15.2) (Backus, R.: unpublished observations).

Shoulder

Anecdotal reports suggest that a rower may commonly exhibit a combination of an anteriorly placed glenohumeral head, tight posterior shoulder capsule, tight latissimus dorsi, and weak rotator-cuff muscles (Richardson & Jull 1995), which may lead to nonspecific shoulder pain.

Forearm and Wrist

Injury to the forearm and wrist can include exertional compartment syndrome (Chumbley 2000), sculler's thumb (Williams 1977), de Quervain disease and intersection syndrome (Hanlon & Luellen 1999), and lateral epicondylitis (Karlson 2000). The most common rowing-specific injury appears to be tenosynovitis due to excessive wrist motion and repeated rotation of the oar twice during each stroke cycle (McNally et al. 2005, Rumball et al. 2005).

Knee

Although women may be predisposed to patellar tracking problems due to anatomical considerations (Karlson 2000), both male and female rowers

Table 15.2 Incidence of rib stress fractures in Canadian national rowing team members from 1991 to 1996.[a]

Year	1991–1992	1992–1993	1993–1994	1994–1995	1995–1996	Overall
Rib fractures	11	0	4	4	4	23
No. training	39	43	43	44	54	223
Incidence	0.28	0.00	0.09	0.09	0.07	0.10

1991–1996	Women	Men
With rib fractures	7	16
No. training	88	135
Incidence	0.08	0.12

1991–1996	Heavyweight	Lightweight
With rib fractures	20	3
No. training	184	39
Incidence	0.11	0.08

1991–1996	Scull	Sweep
With rib fractures	4	19
No. training	39	184
Incidence	0.10	0.10

Data provided by Dr. Richard Backus, Canadian team physician
[a] *Incidence* refers to the number of fractures per athlete.

may have iliotibial band syndrome, due to full knee compression at the catch coupled with varus knee alignment.

Other

Dermatologic issues, including infected blisters, hand warts, sculler's knuckles, slide bites, and rower's rump can commonly develop in the rower (Rumball et al. 2005).

Issues surrounding body composition and the Female Athlete Triad can arise in the lightweight-rowing population (Sykora et al. 1993; Pacy et al. 1995). The Triad is composed of disordered eating, menstrul dysfunction, and lowered bone mineral density, and can often present in elite and recreational atheletes with devastating consequences if left untreated (Lebrun & Rumball, 2002) Wolman et al. (1990) studied 26 elite female rowers, half of whom were amenorrheic, and observed significant differences in bone mineral density between the latter group and the eumenorrheic rowers. These findings may relate to an increased risk of fractures in this population.

Time Loss

Because many elite rowers train and compete full-time, time lost due to injury can have a major impact (Wilson et al., 2004). However, there are few data on rowing injury outcomes. Existing data focuses primarily on back injury, with a few studies documenting the most time lost from training and competition resulting from rib stress fractures (O'Sullivan et al. 2003). Coburn and Wajswelner (1993) documented 54 consecutive rowing injuries over a 12-month period and observed that overall, only 20% of injuries kept rowers out of the boat for longer than 1 week. More recently, Wilson et al. (2004) found a mean land-training time loss of 1 to 2 weeks (23.3%) and a rowing training time loss of 1 to 2 weeks (29.1%) overall.

With respect to low back pain (LBP), Sys et al. (2001) reported that of athletes with spondylolysis, 89.3% returned to sport within an average of 5.5 months after the onset of treatment, and that non-union did not compromise overall outcome. O'Kane et al. (2003) noticed a difference in time lost from training with athletes who had preexisting back pain before their collegiate rowing careers. Of subjects who had preexisting back pain, 79% missed <1 week and 6% missed >1 month. For subjects without preexisting back pain, 62% missed <1 week and 18% missed >1 month. This led the authors to conclude: "While rowers with preexisting back pain are more likely to have back pain in college, they are less likely to miss extended periods of practice time or end their college rowing careers because of back pain."

Stress fractures of the ribs may result in the most time lost from on-water training and competition (Warden et al. 2002), and an estimated 10% to 15% of elite rowers will sustain a stress fracture of a rib at some point in their competitive careers (Hannafin 2000), although these theories have not yet been confirmed in the epidemiologic research.

What Are the Risk Factors?

Very few studies have tested possible risk factors for injury in rowing. To date, the research has focused on height and weight, hypomobility and hyperflexion in the lumbar spine, and training volume.

Intrinsic Factors

Physical Characteristics (Height, Weight, Age)

Rowers are typically tall and lean, with an average height approaching 6′ (women) and 6′6″ (men). Although greater height can contribute to longer stroke lengths (through longer levers), it may also predispose a rower to a higher risk of injury. Teitz et al. (2002) studied 1,632 college rowers and observed that greater height and weight, and beginning the sport prior to 16 years of age, were significant risk factors ($P = 0.03$) for developing LBP. Higher mean college height and weight were significant risk factors in both men ($P = 0.007$ and $P = 0.02$) and women (both $P < 0.001$).

Motor Characteristics (Flexibility, Endurance, Balance, Speed)

Because of the highly technical nature of the rowing stroke, there are many elements of motor coordination, balance, and flexibility that may contribute to the development or prevention of rowing injury.

McGregor et al. (2002) studied 20 elite oarsmen with and without LBP and observed different mobility trends in those with current or previous symptoms. Those with pain demonstrated hypomobility in their lumbar spines, which resulted in increased pelvic rotation. Given the cross-sectional study design, the authors did not know whether these differences in mobility were a result or a cause of LBP.

In a study of LBP in 17 elite lightweight women (Howell 1984), a high positive correlation was found between hyperflexion of the lumbar spine and the incidence of LBP, as well as a high negative correlation between adherence to a regular stretching program and incidence of LBP ($P < 0.005$).

Extrinsic Risk Factors

Coaching, Rules

Two of the risk factors that Teitz et al. (2002) observed while studying LBP in 1,632 college rowers were related to training methods modifiable by coaches: the use of a rowing ergometer for $\geqslant 30$ minutes at a time ($P < 0.001$), and increased training volume using multiple training methods ($P < 0.001$).

What Are the Inciting Events?

The nature of rowing is that from one stroke to the next, different firing patterns, balance issues, timing within the crew, load on the blade, level of fatigue, and many other factors can make it very difficult to pinpoint the precise mechanism of injury.

However, while the term *rowing injury* implies that the injury was sustained during time spent on the water, this is not always the case, making comparison of studies all the more difficult. There are reports that up to 50% of injuries in elite rowers are due to land-based training, including ergometer and weight training (Bernstein et al. 2002; Hickey et al. 1997), and these factors must be taken into consideration. Wilson et al. (2004) observed that running accounted for 14.1% of slow progression and 5.7% of sudden onset injuries.

With respect to weights, Stallard (1980) observed that all cases of back pain in his sample of rowers could be accounted for by weightlifting. Others have also noted a higher incidence of injury in rowers due to weightlifting (Karlson 2000, Warden et al. 2002). Coburn and Wajswelner (1995) noted that of 54 observed rowing injuries, 65% of them occurred from rowing itself and 28% in the weight room, and that weights were the cause of a larger number of lumbosacral injuries (40%) than injuries to the rest of the body (27.8%). More recently, Wilson et al. (2004) reported that 17.2% of injuries were due to weightlifting.

Ergometer training has also been implicated. There is often heavy initial loading at the catch on the rowing ergometer, and elite rowers will often train with low drag factor settings to mimic the feeling inside the boat and to prevent low back injury (McNally et al. 2005). As rowers become fatigued at the end of a long session, the stability of the low back may be impaired (Caldwell et al. 2003; Holt et al. 2003).

Effect of Sculling and Sweeping

Controversy exists surrounding the issue of injury as it relates to the type of rowing. Sculling, which requires two oars, is generally considered a symmetrical motion. Sweeping uses one oar, and requires a slight to extreme rotation of the trunk either to the right or left to achieve adequate stroke length. Although injury occurs in both populations, some researchers have postulated an increased incidence of stress fractures of the ribs in the latter population (Holden & Jackson 1985; Christiansen & Kanstrup 1997; Bojanic & Desnica 1998), while others do not observe any increased risk (Hannafin 2000; Backus R.: unpublished observations). Sacroiliac joint dysfunction, however, may be more common in sweep rowers (66%) than scullers (34%) (Timm 1999).

Stroke Mechanics

Few articles exist that document the effect of movement pattern on injury. However, a study by Vinther et al. (2006) observed differences in stroke mechanics in rowers with a history of stress fractures of the ribs and those without. Rowers with a history of these fractures showed a higher velocity of the seat in the initial drive phase (sequential movement), greater cocontraction of serratus anterior and trapezius muscles, and a reduced leg/arm strength ratio.

Injury Prevention

Although many researchers propose preventive strategies, there are very few who actually provide evidence of such strategies working.

Koutedakis et al. (1997) noted significant negative correlation coefficients between knee-flexion-to-extension peak torque ratios and days off due to low-back injury in both female and male rowers. The authors retested a subgroup of 22 female rowers after introducing a 6- to 8-month hamstring-strengthening program, and observed a reduction of the incidence of low-back injury in the female rowing population.

Further Research

Future research should focus on longitudinal, prospective data collection involving detailed injury reporting on all rowing-specific injuries and their outcomes. This could come from a variety of angles: athlete exposure, equipment changes, risk factors, and sex differences.

With respect to exposure, future studies could follow a group of novice rowers over the course of several seasons to gather data concerning how exposure and advancing levels of training and competition affect injury rates and type. Novice rowers may be predisposed to injury because the boat can often be off-balance, and power application is compromised as a result (McNally et al. 2005). More experienced rowers learn to selectively recruit muscle groups that aid in moving the boat and relaxing those that do not (Yoshiga et al. 2003). Over time, sweep rowers usually specialize on one particular side, which may lead to back pain related to asymmetric muscle development (Stallard 1980; Secher 1993).

In addition, future research could focus on various equipment changes and subsequent forces on anatomical models in controlled environments. Equipment could include different blade designs (such as in Figure 15.2), rigging changes (adjusting load by shortening and lengthening oars or changing the span of the riggers), changes in angle of the foot stretchers and boat design (some hull shapes, while fast, also tend to be less stable than others and could predispose certain rowers to injury).

There are several theories on risk factors that remain hypothetical and need to be substantiated with sound epidemiologic evidence. These include theories for LBP risk factors such as low hamstring-to-quadriceps strength ratio (Koutedakis et al. 1997), strength imbalances in the left and right erector spinae muscles during extension (Parkin et al. 2001), increased demand on the respiratory system (Loring & Mead 1982), and hip muscle imbalances (particularly in female athletes) (Morris et al. 2000). A lack of flexibility and strength is implicated in the development of stress fractures of the ribs as well (Holden & Jackson 1985).

Theoretical strategies to prevent back and rib injury that need to be tested include stretching of hamstring and gluteal muscles and core stability work (McGregor et al. 2002), breathing out during the drive (Manning et al. 2000), anterior rotation of the pelvis (Caldwell et al. 2003), inspiratory muscle training (Voliantis et al. 2001), use of the ergometer for cardiovascular and not strength training, with lower load (Teitz et al. 2003), coaching rowers to avoid stretching loose muscles and having rowers assume positions of lordosis or extension during rest periods (Howell 1984), modifying technique for longer rows (Karlson 2000), and switcing sides for injured sweep rowers (McNally et al. 2005).

All risk factors related to stroke mechanics and other injury also remain theoretical. Stallard (1980) proposed that the great loads placed on the lower

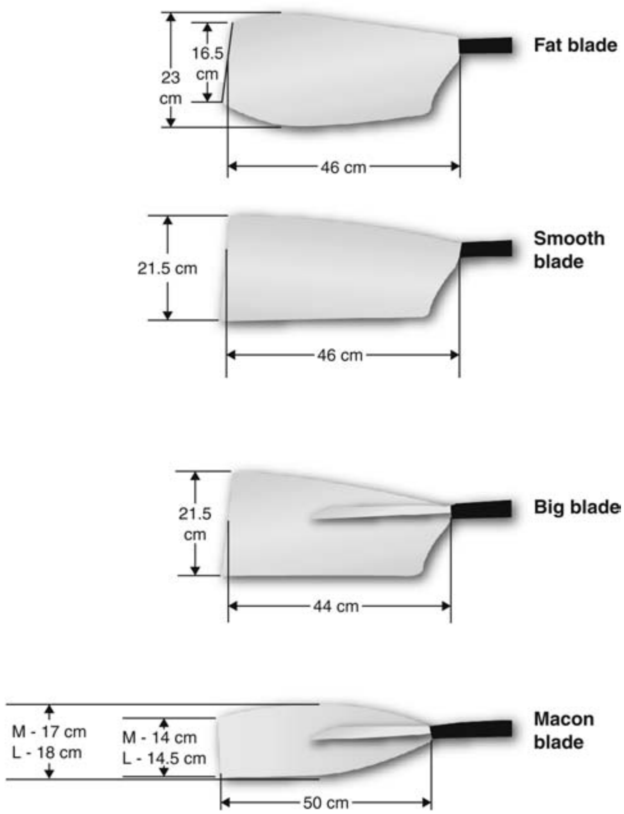

Figure 15.2 Differences in blade shape over the years (most recent at top). L = large; M = medium. Image credit: Dr. Volker Nolte and Concept2 (Morrisville, Vermont).

back at the catch may cause injury, and the amount of lumbar flexion at this part of the stroke cycle may further compound the problem (Bull & McGregor 2000, O'Sullivan et al. 2003, McNally et al. 2005). Poor stroke mechanics have been named as a potential cause for stress fractures of the ribs (Karlson 2000; McKenzie 1989; Read 1994), and repetitive strain through excessive wrist motion may lead to forearm and wrist injury (McNally et al. 2005).

Further research is needed to determine whether there are certain positions during the stroke cycle that predispose the rower to increased rates of injury. The rowing stroke is divided into four main phases: the catch (blade of the oar enters the water, legs and back are fully flexed while arms are fully extended); the drive (power phase of stroke, duing which legs and back are extending and arms are beginning to engage); the finish or release (blade is taken out of the water, legs and back are fully extended, arms are fully flexed); and the recovery (relaxation phase, rower begins to move up in reverse order toward the catch position).

Coaching style at the catch position varies considerably. Some coaches advise a sequential strategy of initiating the drive phase with the legs (knee extension) followed by extension of the hip and back, while research suggests that a more synchronous movement of the legs and trunk may be beneficial (Vinther et al. 2006). The heavy and acute load on the spine that results from a powerful catch may be lessened with a lighter catch and rapid but steady acceleration of the oar (McNally et al. 2005). In addition to technical advice, coaches are usually also responsible for the rigging of the boat, and improper foot angle or placement may contribute to knee injuries (Karlson 2000).

There are obviously significant gaps in the epidemiologic literature of rowing injury to date, which encompass overall incidence, outcome, risk factors, and prevention. The vast majority of the existing research is anecdotal or retrospective, without a clear definition of injury, its duration, or mechanism for onset. In particular, injuries must be reported as whether they were acute or chronic and whether they were sustained during rowing or cross-training. In addition, *low back pain* should be further defined, which will be alleviated by more and better imaging studies in the future. Further studies on the cause of stress fractures of the ribs are also eagerly anticipated. A better understanding of the mechanisms underlying the onset of rowing injury will decrease the incidence of debilitating injury in the future as well as ensuring a faster return-to-sport for the athletes, allowing the sport of rowing to become an even safer and more enjoyable activity for all involved.

References

Adams, M., Dolan, P. & Hutton, W. (1987) Diurnal variations in the stresses on the lumbar spine. *Spine* **12**, 130–137.

Bernstein, I.A., Webber, O., Woledge, R. (2002) An ergonomic comparison of rowing machine designs: possible implications for safety. *British Journal of Sports Medicine* **36**, 108–112.

Bojanic, I. & Desnica, N. (1998) Stress fracture of the sixth rib in an elite athlete. *Croatian Medical Journal* **39**, 458–460.

Bull, A.M & McGregor, A.H. (2000) Measuring spinal motion in rowers: the use of an electromagnetic device *Clinical Biomechanics (Bristol, Avon)* **15**, 772–776.

Caldwell, J.S., McNair, P.J., & Williams, M. (2003) The effects of repetitive motion on lumbar flexion and erector spinae muscle activity in rowers. *Clinical Biomechanics (Bristol, Avon)* **18**, 704–711.

Chumbley, E.M. (2000) Evaluation of overuse elbow injuries. *American Family Physician* **61**, 691–700.

Christiansen, E. & Kanstrup, I.L. (1997) Increased risk of stress fractures of the ribs in elite rowers. *Scandinavian Journal of Medicine and Science in Sports* **7**, 49–52.

Coburn, P. & Wajswelner H. (1993) A survey of 54 consecutive rowing injuries. In: *Conference Proceedings, National Annual Scientific Conference in Sport Medicine* Australian Sports Medicine Federation, Melbourne, p. 85.

Hanlon, D.P. & Luellen, J.R. (1999) Intersection syndrome: a case report and review of the literature. *Journal of Emergency Medicine* **17**, 969–971.

Hannafin, J.A. (2000) Rowing. In: *The Encyclopaedia of Sports Medicine.* Vol. 8, *Women in Sport* (Drinkwater, B., ed.), Blackwell Science, Oxford, pp. 486–493.

Hickey, G.J., Fricker, P.A., & McDonald, W.A. (1997) Injuries to elite rowers over a 10-yr period. *Medicine and Science in Sports and Exercise* **29**, 1567–1572.

Holden, D., & Jackson, D.W. (1985) Stress fractures of the ribs in female rowers. *Sports Medicine* **13**, 342–348.

Holt, P.J., Bull, A.M., Cashman, P.M. & McGregor, A.H. (2003) Kinematics of spinal motion during prolonged rowing. *International Journal of Sports Medicine* **24**, 597–602.

Howell, D.W. (1984) Musculoskeletal profile and incidence of musculoskeletal injuries in lightweight women rowers. *American Journal of Sports Medicine* **12**, 278–283.

Karlson, K.A. (1998) Rib Stress Fractures in Elite Rowers: A Case Series and Proposed Mechanism. *American Journal of Sports Medicine* **26**, 516–519.

Karlson, K.A. (2000) Rowing injuries. *The Physician and Sportsmedicine* **28**, 40–50.
Koutedakis, Y., Frischknecht, R. & Murthy, M. (1997) Knee flexion to extension peak torque ratios and low-back injuries in highly active individuals. *International Journal of Sports Medicine* **18**, 290–295.
Lebrun, C.M., Rumball, J.S. (2002) Female Athlete Triad. *Journal of Sports Medicine and Arthroscopy Review* **10**, 23–32.
Loring, S.H. & Mead, J. (1982) Action of the diaphragm on the rib cage inferred from a force-balance analysis. *Journal of Applied Physiology* **53**, 756–760.
Manning TS, Plowman SA, Drake G, et al. Intra-abdominal pressure and rowing: the effects of inspiring versus expiring during the drive. *J Sports Med Phys Fitness* 2000; **40** (3): 223-32.
McGregor, A., Anderton, L., Gedroyc, W. (2002) The assessment of intersegmental motion and pelvic tilt in elite oarsmen. *Medicine and Science in Sports and Exercise* **34**, 1143–1149.
McKenzie, D.C. (1989) Stress fracture of the rib in an eilte oarsman. *International Journal of Sports Medicine* **10**, 220–222.
McNally, E., Wilson, D. & Seiler, S. (2005) Rowing injuries. *Seminars in Musculoskeletal Radiology* **9**, 379–396.
Morris, F.L., Smith, R.M., Payne, W.R., Galloway, M.A., & Wark, J.D. (2000) Compressive and shear force generated in the lumbar spine of female rowers. *International Journal of Sports Medicine* **21**, 518–523.
O'Kane, J.W., Teitz, C.C., & Lind, B.K. (2003) Effect of preexisting back pain on the incidence and severity of back pain in intercollegiate rowers. *American Journal of Sports Medicine* **31**, 80–82.
O'Sullivan, F., O'Sullivan, J., Bull, A.M. & McGregor, A.H. (2003) Modelling multivariate biomechanical measurements of the spine during a rowing exercise. *Clinical Biomechanics (Bristol, Avon)* **18**, 488–493.
Pacy, P.J., Quevedo, M., Gibson, N.R., Cox, M., Koutedakis, Y. & Millward, J. (1995) Body composition measurement in elite heavyweight oarswomen: a comparison of five methods. *Journal of Sports Medicine and Physical Fitness* **35**, 67–74.
Parkin, S., Nowicky, A.V., Rutherford, O.M., et al. (2001) Do oarsmen have asymmetries in the strength of their back and leg muscles? *Journal of Sports Science* **19**, 521–526.
Read, M.T.F. (1994) Case report: stress fracture of the rib in a golfer. *British Journal of Sports Medicine* **28**, 206–207.
Reid, R., Fricker P.A., Kestermann, O., Shakespear, P. (1989) A profile of female rowers' injuries and illnesses at the Australian Institute of *Sport Excel* **5**, 17–20.
Reid, D.A. & McNair, P.J. (2000) Factors contributing to low back pain in rowers. *British Journal of Sports Medicine* **34**, 321–325.
Richardson, C. & Jull, G. (1995) Muscle control: what exercises would you prescribe? *Manual Therapy* **1**, 2–10.
Rossi, F. & Dragoni, S. (1990) Lumbar spondylolysis: occurrence in competitive athletes. Updated achievements in a series of 390 cases. *Journal of Sports Medicine and Physical Fitness* **30**, 450–452.
Roy, S.H., De Luca, C.J., Snyder-Mackler, L., Emley, M.S., Crenshaw, R.L. & Lyons, J.P. (1990) Fatigue, recovery, and low back pain in varsity rowers. *Medicine and Science in Sports and Exercise* **22**, 463–469.
Rumball, J.S., Lebrun, C.M., DiCiacca, S., Orlando, K. (2005) Rowing Injuries. *Sports Medicine* **35**, 537–555.
Secher, N.H. (1993) Physiological and biomechanical aspects of rowing: implications for training. *Sports Medicine* **15**, 24–42.
Seiler, K.S, Spirduso, W.W. & Martin, J.C. (1998) Gender differences in rowing performance and power with aging. *Medicine and Science in Sports and Exercise* **30**, 121–127.
Seiler, S. (2004) Masters rowers—who were they, who are they, and why do they love it so much? Presented at the International Rowing Federation Joint Meeting of Developmental Committees; London, United Kingdom.
Soler, T. & Calderon, C. (2000) The prevalence of spondylolysis in the Spanish elite athlete. *American Journal of Sports Medicine*, **28**, 57–62.
Stallard, M.C. (1980) Backache in oarsmen. *British Journal of Sports Medicine* **14**, 105–108.
Sykora, C., Grilo, C.M., Wilfley, D.E. & Brownell, K.D. (1993) Eating, weight, and dieting disturbances in male and female lightweight and heavyweight rowers. *International Journal of Eating Disorders* **14**, 203–211.
Sys, J., Michielsen, J., Bracke, P., Martens, M. & Verstreken, J. (2001) Nonoperative treatment of active spondylolysis in elite athletes with normal x-ray findings: literature review and results of conservative treatment. *European Spine Journal* **10**, 498–504.
Teitz, C.C., O'Kane, J., Lind, B.K. & Hannifin, J.A. (2002) Back pain in intercollegiate rowers. *American Journal of Sports Medicine* **30**, 674–679.
Teitz, C.C., O'Kane, J. & Lind, B.K. (2003) Back pain in former intercollegiate rowers: a long-term follow-up study. *American Journal of Sports Medicine* **31**, 590–595.
Thomas, P.L. (1988) Thoracic back pain in rowers and butterfly swimmers: costovertebral subluxation. *British Journal of Sports Medicine* **2**, 81.
Timm, K.E. Sacroiliac joint dysfunction in elite rowers. (1999) *Journal of Orthopaedic Sports and Physical Therapy* **29**, 288–295.
Urban, J. & McMullin, J. (1988) Swelling pressure of the lumbar intervertebral disc: influence of age, spinal level, composition and degeneration. *Spine* **13**, 179–187.
Vinther, A., Kanstrup, I.L., Christiansen, E., Alkjaer, T., Larsson, B., Magnusson, S.P., Ekdahl, C., Aagaard, P. (2006) Exercise-induced rib stress fractures: potential risk factors related to thoracic muscle co-contraction and movement pattern. *Scandinavian Journal of Medicine and Science in Sports* **16**, 188–196.
Voliantis, S., McConnell, A.K., Koutedakis, Y., et al. (2001) Inspiratory muscle training improves rowing performance. *Medicine and Science in Sports and Exercise* **33**, 803–809.
Wajswelner, H., Mosler, A. & Coburn, P. (1995) Musculoskeletal injuries in domestic and international rowing. In *Conference Proceedings, Australian Conference of Science and Medicine in Sport*, Hobart, Australia, p. 382.
Warden, S.J., Gutschlag, F.R., Wajswelner, H. & Crossley, K.M. (2002) Aetiology of rib stress fractures in rowers. *Sports Medicine* **32**: 819–836.
Weightman, D. & Browne, D.M. (1975) Injuries in eleven selected sports. *British Journal of Sports Medicine* **9**, 136–141.
Williams, J.G.P. (1977) Surgical management of traumatic non-infective tenosynovitis of the wrist extensors. *Journal of Bone and Joint Surgery, British* **59**, 408–410.
Wilson, F., Kennedy, F. & Meehan, K. (2004) The incidence and management of rowing injuries. (Part II: interdisciplinary) *Journal of Sports Sciences* **22**, 261–262.
Wolman, R.L., Clark, P., McNally, E., Harries, M. & Reeve, J. (1990) Menstrual state and exercise as determinants of spinal trabecular bone density in female athletes. *British Medical Journal* **301**, 516–518.
Yoshiga, C.C., Higuchi, M. & Oka, J. (2003) Lower heart rate response to ergometry rowing than to treadmill running in older men. *Clinical Physiology and Functional Imaging* **23**, 58–61.

Chapter 16

Sailing

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Introduction

The sport of sailing has evolved from one of the oldest means of transport, dating back over 5,000 years. Today, sailing is enjoyed worldwide from the occasional recreational enthusiast to elite Olympic-class competitors and professional big-boat sailors. It is estimated that more than 16 million people participate in sailing activities worldwide. The earliest record of modern-day sailboat racing was the first America's Cup challenge around the Isle of Wight in 1851 (Whiting 2007). In fact, the America's Cup is the oldest competing trophy in modern sport, predating the Modern Olympics by 45 years.

Sailing was included in the inaugural Modern Olympic Games in Athens in 1896, but the regatta was canceled because of adverse weather conditions. Hence, the first Olympic medals for sailing were awarded at the 1900 Olympic Games. The design or class of boats has changed over the years, with the Star class being the oldest current Olympic-class boat; first introduced for the 1932 Games. The first women's Olympic sailing event was introduced for the 1988 Olympic Games in Seoul with the 470 two-person Dinghy; an additional two women's classes were added in 1992. Windsurfing originated in the late 1960s, and has been one of the fastest-growing sports in the World, to the extent that today there are more participants in windsurfing than all other types of sailing combined. Windsurfing first joined the Olympic Games in 1984 and is regarded as one of the most athletically demanding and exciting sailing events.

There are currently nine one-design class boats for the 11 Olympic-class sailing events. The term *one-design* implies that the boats in each class are identical, having been manufactured under strict International Sailing Federation (ISAF) specifications, ensuring that the skill of the athlete is tested rather than the design of the boat.

Many Olympic-class sailors go on to become professional big-boat sailors in prestigious elite team events such as the America's Cup and the Volvo Ocean Race (formerly the Whitbread Round-the-World Race). The increased interest in competitive sailing has led to a rise in commercialization and professionalism at the elite levels of competition, with clear increases in the physiological and psychological demands placed on competitive sailors. The demands and technical requirements of sailing at all levels depend largely on the class of boat, the sailors role on board, the level of competition, and the weather conditions. As with most other athletes, sailors are at risk of injury (Neville et al. 2006) and an understanding of the risks is important in helping to reduce the burden of sailing injuries (whether it be financial, performance, health, or otherwise).

The aim of this chapter is to review the literature on sailing and to provide a detailed report on the risks, distribution, and mechanisms of injury, as well

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as suggested injury-prevention strategies and directions for future research. Most studies reviewed were descriptive in nature, with few reports having quantitatively measured sailing exposure. Thus, incidence rates are mostly estimated or based on data collected from retrospective questionnaires. In addition, the considerable variation in research methods, particularly with respect to the definition of injury, the specificity of cohorts, the classification of injury, and the clarity of injury diagnosis, makes comparison between studies difficult. Moreover, the dearth of data on Olympic-class sailing injuries is surprising, considering the interest there has been in the physiological and biomechanical demands of Olympic-class sailing in recent years (Mackie et al. 1999; Bojsen-Moller et al. 2007; Cunningham & Hale 2007; Vangelakoudi et al. 2007).

Who Is Affected by Injury?

The incidence of injury varies according to the class of sailing; Olympic-class (McCormick & Davis 1988; Legg et al. 1997b; Nathanson & Reinert 1999; Schaefer 2000; Dyson et al. 2006), recreational sailing (Nathanson et al. 2006), and big-boat sailing (Price et al. 2002; Spalding et al. 2005; Neville et al. 2006) are shown in Table 16.1. Most studies are based on retrospective questionnaires, with few having accurately measured exposure. In fact, there is only one prospective study in the literature to date that has comprehensively reported incidence data for injuries in sailing (Neville et al. 2006). However, some studies have included the frequency of injuries over a specific period of time, such as during a particular competition (Price et al. 2002; Spalding et al. 2005) or over a year (Legg et al. 1997b; Schaefer 2000; Dyson et al. 2006; Nathanson et al. 2006). Based on these data it seems that professional big-boat sailors are at greater risk of injury (3.1 to 3.2 injuries per year) (Spalding et al. 2005; Neville et al. 2006) than other classes of sailing (0.2 to 2.0 injuries per year) (Legg et al. 1997b; Dyson et al. 2006; Nathanson et al. 2006; Schaefer 2000). However, these large differences may be due to the wide variations in methods and definitions used in injury surveillance studies.

Position

The physiological demands of sailing are position- and boat-specific (Legg et al. 1997a; Bernardi et al. 2007), and the risk of injury is associated with the specific activities performed. In elite Olympic-class sailing, the positions that predominantly involve hiking are at greatest risk of injury. This is the helmsman in the one-person classes such as the Laser, Finn, Laser Radial, and NeilPryde RS:X and the crew in two- or three-person classes, such as the 470, Star, Yngling, and 49er. In novice sailing (Schaefer 2000), however, it is the helmsman who is at greatest risk of impact with the boom or mainsheet. In America's Cup sailing (Allen 1999; Allen 2005; Neville et al. 2006), the bowmen and the grinders are at greatest risk of injury. Neville et al. (2006) reported an incidence of 3.2 and 3.1 injuries per 1,000 hours of sailing for bowmen and grinders, respectively. These results are not surprising, considering the high frequency of activities performed by the bowmen along the narrow foredeck and the high intensity and volume of grinding performed by the grinders (Miller 1987, Neville et al. 2003, 2006). Helmsmen, on the other hand, have few physical stressors other than neck, shoulder, and lower back fatigue, resulting from prolonged standing and concentration, which is evident in the relatively low risk of injury (0.4 per 1,000 hours of sailing) (Neville et al. 2006). Conversely, off-shore racing helmsmen have a higher risk of injury (2.6 injuries per race leg) (Spalding et al. 2005) because of the arduous nature of steering in heavy weather conditions. Most positions in off-shore racing have a similar risk of injury; ranging from 1.7 to 3.1 injuries per leg of the race (Spalding et al. 2005).

Sex

There is little evidence to suggest any difference in the risk of injury between male and female sailors. Of the 238 minor injuries incurred by novice Dinghy sailors, Schaefer (2000) reported that the risks of injury in men and women were similar, as were the nature and type of injuries. In windsurfing, Ullis & Anno (1984) reported similar types of injuries for men and women, although men had a greater incidence of serious injuries. McCormick and Davis

Table 16.1 Comparison of injury rates by sailing class.

Study	Design of Study	Class Description	Standard of Competition	No. of Athletes	No. of Injuries	Duration	No. of Injuries per 1,000 Days of Sailing	No. of Injuries per 1,000 Hr of Exposure	No. of Injuries per Year per Athlete
Olympic Class									
Legg et al. (1997b)	RQ	Finn, Laser, 470, Europe, Tornado, Mistral	Elite	28	20	3 yr	—	—	0.2
Schaefer (2000)	RQ	Dinghy	Novice	536	238	1 yr	—	0.29	0.4
Dyson et al. (2006)	RQ	Windsurfing (Race–board)	Elite	36	76	2 yr	—	—	1.1
	RQ	Windsurfing (Wave–slalom)	Elite	43	173	2 yr	—	—	2.0
	RQ	Windsurfing (Boardsail)	Recreational	28	67	2 yr	—	—	1.2
Nathanson & Reinert (1999)	WebS	Windsurfing	Mixed	294	489	—	1.0	—	
McCormick & Davis (1988)	RQ	Windsurfing	Mixed	73	104	Career	—	0.22	—
Recreational Sailing									
Nathanson et al. (2006)	WebS	Mixed classes	Recreational	1431	1756	—	18.9	—	0.7
Big-Boat Sailing									
Neville et al, (2006)	P	America's Cup (2003)	Professional	35	220	2 yr	—	5.70	3.1
Spalding et al. (2005)	RQ	Volvo Ocean Race	Professional	97	312	9 mo	—	—	3.2
Price et al. (2002)	RQ	Global Challenge	Amateur	365 (195)[a]	299	10 mo	—	0.37	1.5

RQ = retrospective questionnaire; P = prospective; WebS = Internet survey.
[a] During the race, 365 sailors were rotated in and out for the 195 crew positions.

(1988), however, reported that during strong wind conditions, female windsurfers had a greater incidence of injury (0.37 per 1,000 hours; n = 22) than male windsurfers (0.17 per 1,000 hours; n = 51). Unfortunately, big-boat sailing reports that have included data on injuries in women (Allen 1999; Spalding et al. 2005) have failed to include incidence or comparative data; hence, it is difficult to determine any difference in risk.

Where Does Injury Occur?

Anatomical Location

The distribution of injuries by anatomical location appears to be specific to the sailing class (Table 16.2). In elite-level Olympic-class sailing (Legg et al. 1997b; Moraes et al. 2003), the body parts most frequently injured are the spine, followed by the knee. A retrospective questionnaire on 28 elite New Zealand Finn, Tornado, Laser, Europe, 470 and Mistral sailors during preparation for the 1996 Olympic Games (Legg et al. 1997b) identified the lumbar spine as the most commonly injured body part during the previous 3 years, followed by the knee, shoulder, and upper limb. Experienced Dinghy and Keelboat sailors "hike" (lean) out of the boat for prolonged periods to counterbalance the heel force exerted by the wind (Figure 16.1). The force exerted on the foot strap of Laser sailors while hiking in 15 knots of wind can be in excess of 800 N (Mackie & Legg 1999). This force is translated mainly to the knee and lumbar spine (Newton 1989; Mackie & Legg 1999), thereby increasing the stress and associated risk of injury to these structures. In contrast, novice Dinghy sailors are typically less proficient at hiking and have a greater percentage of upper-limb, mainly the hand, and head injuries as a result of impact with and use of equipment (Schaefer 2000). Windsurfing injuries occur predominantly to the lower limbs and lower back (Ullis & Anno 1984; Allen & Locke 1989; Nathanson & Reinert 1999; Dyson et al. 2006). Dyson et al. (2006) reported the lower limbs to be the most frequently injured body region (39%), specifically, the thigh and calf and the ankle and foot, followed by the lumbar spine and shoulder. Most lower-limb injuries in windsurfing are the result of falling with the feet caught in the foot straps or contact with the center board or skeg (Ullis & Anno 1984; Allen & Locke 1989; Nathanson & Reinert 1999). Lower-back injuries in windsurfing are thought to be due to maintaining lumbar extension (lordotic posture) for prolonged periods and possibly the lumbar compression involved when sailing without the use of a harness, which attenuates the force transmitted through the spine (Locke & Allen 1992; Rosenbaum & Dietz 2002).

The anatomical location of injury in big-boat sailing seems consistent, regardless of the sailing class. The spine and torso are at greatest risk of injury (21–43%), followed by the upper limbs (22–39%) (Allen 1999, 2005; Neville et al. 2006; Spalding et al. 2005, Price et al. 2002).

Environmental Location

In professional sailing, land-based strength and conditioning training plays a major role in preparing athletes for the high physical demands of racing (Bernardi et al. 2007). Hence, the intensity of training is often higher than that of sailing (Neville et al. 2006). It is not surprising, then, that in one report on the America's Cup, the incidence of injury during strength and conditioning training was greater than that during sailing (8.6 vs. 2.2 injuries per 1,000 hours) (Neville et al. 2006). Furthermore, contrary to many other sports, the incidence of injury during the America's Cup competition period was lower than during the training periods (4.7 vs. 6.2 injuries per 1,000 hours) (Neville et al. 2006). This lower risk may be due to the reduced volume and intensity of training during the competition period.

Environmental conditions, particularly wind speed, have been reported to affect the risk of injury (Vogiatzis et al. 1995; Schaefer 2000). In recreational sailing, 18% (316 of 1,756) of injuries reported in an Internet-based survey (Nathanson et al. 2006) occurred as a direct result of high wind speeds. Schaefer (2000) Thirty-four percent of injuries in novice sailors (81 of 238) occurred when wind speeds were above 17 knots, and less than 9% (21 of 238) occurred at wind speeds below 7 knots, even though the percentage exposures was similar (22% and 24%, respectively) (Schaefer 2000). During off-shore racing, the stages covering the southern ocean, where the roughest sea conditions were

Table 16.2 Percentage distribution of injuries by anatomical location.

	Olympic-Class Sailing			*Windsurfing*			*America's Cup*			*Off–Shore Racing*	
	Legg et al. (1997)	Schaefer (2000)	Moraes et al. (2003)[a]	Ullis & Anno (1984)[a]	Nathanson & Reinert (1999)	Dyson et al. (2006)	Neville et al. (2006)	Allen (2005)	Allen (1999)	Spalding et al. (2005)	Price (2002)
No. of Incidents	20	238	–	511	489	262	220	206	54	312	229
Head and Face	–	***32***	–	***56***	***18***	***7***	***2***	–	–	–	***12***
Spine and Torso	–	***2***	–	–	***16***	***22***	***30***	–	***43***	***42***	***21***
Neck	–	–	24	51	–	3	11	8	13	11	–
Thoracic spine	–	–	41	–	–	5	6	6	–	10	–
Ribs	–	–	–	40	–	3	2	–	–	–	–
Lumbar spine	45	–	53	79	–	11	12	16	30	21	–
Upper Extremity	–	***40***	–	–	***19***	***33***	***26***	–	***38***	***39***	–
Shoulder	18	–	24	40	–	11	18	16	16	15	6
Arm	15	2	21	61	–	7	8	–	–	11	–
Elbow	–	3	21	30	–	9	8	–	11	13	–
Hand and fingers	–	35	–	49	–	5	7	7	–	–	16
Lower Extremity	–	***26***	–	–	***45***	***39***	***19***	–	***13***	***18***	–
Hip	–	–	–	–	–	2	6	–	–	5	–
Leg	–	13	27	78	–	17	6	–	–	–	–
Knee	22	12	34	40	–	4	5	10	11	8	9
Ankle and foot	–	–	–	95	–	16	8	–	–	5	8

[a] Values expressed as percentage of all athletes as opposed to percentage of injuries.

Figure 16.1 Helmsman and crew hiking off the side of a two-person Olympic class keelboat (Star) showing the position of the knee during prolonged hiking. Courtesy of Getty Images.

experienced, had significantly more injuries than other stages ($P = 0.02$; Price et al. 2002). In windsurfing the risk of injury is greater when sailing in "hurricane" conditions of 40 knots (McCormick & Davis 1988). Interestingly though, chronic lower back pain in windsurfers occurs predominantly during lighter wind conditions (Locke & Allen 1992), because of maintaining a prolonged lordotic posture.

When Does Injury Occur?

Injury Onset

Most sailing injuries can be characterized as either acute or chronic in nature, as a result of macro-traumatic or micro-insidious forces. Acute injuries, resulting from a sudden trauma, include contusions, fractures, strains, and sprains, whereas chronic injuries, resulting from prolonged or repetitive overloading, include tendinopathies, sprains, neuropathies, and bursitis (Peterson & Renstrom 2001). The nature of injury seems to be specific to the sailing class (Allen 1999, 2005; Allen & Locke 1989; Nathanson & Reinert 1999; Neville et al. 2006). Most windsurfing injuries (~70%) are acute (Allen & Locke 1989; Nathanson & Reinert 1999), mainly as a result of impact with equipment. In professional big-boat sailing, Neville et al. (2006) reported that two thirds of injuries (148 of 220) in a 2-year America's Cup campaign were acute. However, the severity of chronic injuries (predominantly tendinopathies) was significantly greater than acute injuries (6.1 vs. 3.4 days absent per injury), which was attributed to the demands of high-repetition activities. In contrast, a pilot study on an all-female team (America[3]) competing in the 1995 America's Cup (Allen 1999), showed a greater percentage of overuse injuries and muscle strains than an all male crew (overuse, 68% vs. 33%; strains, 33% vs. 12%; female vs. male, respectively). These differences are postulated to be the result of differences in experience and the high absolute demands of this sailing class subjecting females to higher relative loads, but they could also be due to discrepancies in injury definition and data-collection methods.

Unfortunately, there are few data available on the nature of injury in Olympic-class sailing. It appears that the type of injury may be related to the skill level of the athlete. Elite Olympic-class sailors appear to be at greater risk of overuse injuries (Legg et al. 1997b), whereas novice Dinghy sailors are predominantly at risk of acute trauma (95% of all injuries) (Schaefer 2000). This may be related to a number of factors, including the level of conditioning and skill development (Vangelakoudi et al. 2007), the risk of contact with hardware, and the highly repetitive nature of specific activities.

In some sailing classes, the nature of injury may vary according to crew position; for example, off-shore racing helmsmen experience mostly overuse injuries to the upper limb, whereas mastmen and bowmen are at greater risk of acute injuries (Spalding et al. 2005).

What Is the Outcome?

Injury Type

The type of injury sustained is related to the sailing class, as well as the level of sailing experience. In a study of 536 novice Dinghy sailors (Schaefer 2000), contusions and bruises were the most common injuries (61% [146 of 238]), followed by abrasions and lacerations (32% [75 of 238]). Similar findings have been confirmed by an online survey of recreational sailors using a variety of boats (Nathanson et al. 2006). In contrast, elite Olympic-class sailors experience more strains and sprains, considered to be as a result of repetitive and prolonged activities such as hiking and trimming (Legg et al. 1997b; Moraes et al. 2003), although these reports failed to include quantitative data.

In windsurfing, the types of injuries are similar between elite (Allen & Locke 1989) and recreational boardsailors (McCormick & Davis 1988), with abrasions (23–63% of athletes), lacerations (29–59%), and strains (19–59%) being most frequent. One survey of 107 windsurfers over a 2-year period (Dyson et al. 2006), reported muscle strains as the most common injury in wave-slalom (32%), race-boarders (45%), and recreational windsurfers (30%). Lacerations and abrasions were also common for wave-slalom windsurfers and ligament sprains for recreational windsurfers. Forearm neuropathies (Ciniglio et al. 1990; Jablecki 1999) have also been reported in windsurfers, as a result of prolonged and repeated elbow flexion and forearm pronation (Dyson et al. 1996).

During elite America's Cup sailing, Neville et al. (2006) found contusions, sprains, and tendinopathies to be the most frequent injury types. In off-shore racing (Bugge 1986; Price et al. 2002), the majority of injuries are impact injuries, such as contusions and lacerations (38–47%), fractures (11–18%) and sprains (9–23%). Tendinopathies and neuropathies also appear to be common for helmsmen in this class (Spalding et al. 2005).

Injury Severity

Few studies have discussed the severity of injury in relation to training or competition time lost.

The severity of injury is often specific to the class of boat or the role of the athlete. For example, patellofemoral pain syndrome may prevent a Finn or Laser sailor from sailing (Newton 1989; Cockerill 1999), but this is not necessarily the case for an America's Cup afterguard. The severity of injury is therefore related to the demands of the specific activities performed. In recreational sailing, only half of all injuries reported by Nathanson et al. (2006) required first-aid or medical care. Similarly, Schaefer (2000) reported an incidence of 17.1 injuries per 1,000 hours in novice Dinghy sailors; however, when minor injuries (234 of 238) were excluded, the incidence of severe injuries was just 0.29 injuries per 1,000 hours. Therefore, focusing attention on the risks of these 2% of injuries may be most effective in attenuating the impact of injury. There seems to be a relatively high risk of severe injuries in windsurfing (Ullis & Anno 1984), with 21% (9 of 43) of one cohort of competitive male windsurfers having been admitted to the hospital for treatment at some point in their career. These severe injuries included knee ligament sprains, vertebral fractures and disk herniations, lacerations, ruptured knee ligaments, shoulder dislocations, elbow epicondylitis, infected wounds, pneumothorax, carpal tunnel syndrome, and eardrum perforation and were frequently associated with advanced maneuvers of wave-jumping and wave-sailing (Dyson et al. 2006). In contrast, a study by McCormick and Davis (1988) found that of the 76% of recreational windsurfers with injuries who were questioned, only 15% of the injuries were severe (i.e., required medical treatment). Overuse neuropathies, such as lateral antebrachial cutaneous syndrome (Jablecki 1999) and radial tunnel syndrome (Ciniglio et al. 1990) have also been documented as severe windsurfing injuries.

Neuropathies and tendinopathies are not uncommon in big-boat sailing (Neville et al. 2003, 2006; Molloy et al. 2005; Spalding et al. 2005). Neville et al. (2003) reported two incidents of posterior interosseous-nerve entrapment (PINE) in one team of 35 professional sailors during the 2-year preparation for the 31st America's Cup (0.1 per 1,000 hours), with a mean consequence of 13 days absent from sailing and 37 days absent from weight-training for each incident. Similarly, wrist tenosynovitis resulted in 15 days' absence from sailing per incident (Neville et al. 2006). Injuries resulting in the greatest absence from America's Cup sailing were chronic overuse injuries: cervical spine degeneration (21%), PINE (7%), lumbar spine abnormalities (6%), and biceps tendinopathy (4%) (Neville et al. 2006). Spalding et al. (2005) also reported that off-shore helmsmen were at risk of severe overuse injuries (shoulder rotator-cuff impingement, wrist tenosynovitis, carpal tunnel syndrome), all of which affected their performance or participation.

Sailing Fatalities

Although relatively uncommon, fatal incidents have been reported in both elite and recreational sailing. A total of five fatalities have occurred during the past nine Volvo Ocean Races (formerly, the Whitbread Ocean Race), mostly as a result of being washed overboard in rough sea conditions. The Canadian national boating fatalities report between 1996 and 2000 (LifesavingSociety 2003) reported that <4% (32 of 888) of all water-related deaths were due to sailing, whereas an Australian national analysis of fatal boating incidents reported that 36% (86 of 241) of fatalities occurred while Dinghy sailing (O'Connor 2008). ISAF recently legislated on the use of quick-release harnesses during competition after several entrapment incidents and three fatalities involving Dinghy trapeze harnesses (Thorn 2007).

What Are the Risk Factors?

In sailing, the causal factors predisposing an athlete to injury are often difficult to determine, as a large proportion of injuries are insidious and occur as a result of complex interactions of various risk factors. Most often, the risk of injury is the result of an interaction between an athlete's physical and psychological characteristics and the environment (van Mechelen et al. 1992). Very few analytical data are available on the risks of injuries in sailing, particularly relating to intrinsic factors such as sex, age, sailing experience, and conditioning. For the extrinsic risk factors, apart from the class of boat and the role of the athlete, the wind conditions have been shown to play an influential part in the physical and technical demands (Vogiatzis et al. 1995) and subsequent injury risk.

What Are the Inciting Events?

Identifying the inciting mechanisms of sailing injuries is important in determining preventive-reatment strategies. Although some activities in sailing are similar regardless of the class of boat, many are specific, such as "hiking" (Olympic class sailing) (Figure 16.1), "pumping" (Olympic-class sailing and windsurfing), "grinding," and "steering" (big-boat sailing). In elite Olympic-class sailing (Legg et al. 1997b; Shephard 1997; Newton 1989), prolonged hiking is the main cause of knee injury, particularly when the knee is in sustained flexion (Newton 1989). A substantial number of cases (23) of radial-nerve syndrome were reported by Ciniglio et al. (1990) as a result of prolonged elbow flexion and forearm pronation while pumping the sail when windsurfing. A similarly complex insidious elbow injury, termed "grinder's elbow" by Miller (1987) and later diagnosed as PINE by Neville et al. (2003), appears to be the result of excessive repetitive grinding and top-handle winching on America's Cup–class boats. Steering or "helming" is typically regarded as one of the least-demanding activities in most sailing classes; however, in off-shore racing, particularly in heavy weather conditions of the Southern Ocean, it is one of the more arduous activities, predisposing helmsmen (89%) to upper-limb overuse injuries (Spalding et al. 2005).

Equipment

As sailing relies on the interaction between athlete and hardware, and often in unstable and unpredictable conditions, it is not surprising that equipment is a major contributing factor to many injuries. In particular, recreational and novice sailors

(Schaefer 2000; Nathanson et al. 2006) are at greatest risk of injury as a result of impact with hardware (22–51%), most notably, the boom or mainsheet (31%) (Schaefer 2000). Other severe but less common injuries occur during lowering of the keel in the boat (hand/finger lacerations and fractures). Hence, it is these areas in which the greatest investment of preventive resources should be allocated. Adverse interactions with equipment are also responsible for a high proportion (45%) of windsurfing injuries (Nathanson & Reinert 1999)— for example, falling with feet caught in the foot straps, or impact with the center board, skeg or mast (Ullis & Anno 1984; Allen & Locke 1989; Nathanson & Reinert 1999; Dyson et al. 2006). The boom shape and diameter has also been suggested to contribute to forearm overuse injuries in windsurfing (Ciniglio et al. 1990; Jablecki 1999). Depending on hand size and grip strength, a larger-diameter boom requires greater grip strength, which could prematurely fatigue forearm muscles. Athletes' trapeze harnesses have also been associated with a number of fatalities and entrapment incidents in Dinghy sailing (Thorn 2007).

In America's Cup sailing (Neville et al. 2006), impact with boat hardware accounts for 15% of all injuries, with pulling and lifting sails accounting for a further 5%. Low grinding pedestals have also been suggested to increase the risk of lumbar spine injuries in grinders (Allen 1999; Neville et al. 2006). A third of all off-shore racing injuries occur below deck (Price et al. 2002; Spalding et al. 2005), because of the greater volume of time spent below deck and the violent and sudden movements of the yachts during heavy weather. In addition, Spalding et al. (2005) reported that all helmsmen with carpal tunnel syndrome (17% of helmsmen) used polished carbon steering wheels, as opposed to fabric-grip wheels as were used by the noninjured helmsmen. The smooth surface requires the helmsmen to grip the wheel harder, particularly when wet, thus increasing forearm stress.

Technique

In elite Olympic-class sailing, poor hiking technique and inadequate strength can predispose the knee to injury (Newton 1989; Legg et al. 1997b; Shephard 1997; Bojsen-Moller et al. 2007). In certain classes, such as Finn sailing it is extremely difficult to maintain a straight-leg position when hiking, which results in greater forces being exerted on the knee joint (Newton 1989). In other classes, in which straight-leg hiking is predominantly performed, such as in Laser sailing, greater loads are placed on the quadriceps muscles and on the lumbar spine (Newton 1989; Cockerill 1999; Mackie et al. 1999; Bojsen-Moller et al. 2007). However, there are few data to suggest any increased risk of quadriceps injury in sailors. Foot placement is also important when hiking, as internal rotation of the leg promotes overdevelopment of the vastus lateralis muscle (Cockerill & Taylor 1998), increasing lateral tracking of the patella and predisposing the athlete to chronic knee pain (e.g. chondromalacia patella).

In big-boat sailing, incorrect grinding technique has been postulated as a risk factor for upper-limb overuse injuries (Neville et al. 2003; Molloy et al. 2005), particularly if the upper extremity, rather than the lower extremity and trunk, is relied on as the force generator. Similarly, off-shore helmsmen who steer with the upper arm in shoulder flexion and abduction are at greater risk of supraspinatus impingement injury, where as those adopting an adducted shoulder position with elbow flexion are at greater risk of wrist tenosynovitis (Spalding et al. 2005). Furthermore, most activities performed in big-boat sailing require forward flexion of the spine with repetitive lumbar rotation and often during strenuous exercise and high load conditions (Neville et al. 2006), thereby placing the structures of the lumbar spine under tremendous strain and increased risk of injury (Bono 2004).

Injury Prevention

One of the most important topics in sport is that of injury prevention. The literature on sailing-injury prevention is restricted to a few informative descriptive reports and expert opinions (Blackburn 1994; Cockerill & Taylor 1998; Cockerill 1999; Scott 2001; Crafer 2004), with no published intervention studies. Hence, there is a need for well-controlled studies on injury-prevention measures to understand the effectiveness of proposed interventions. A number of proposed injury-prevention strategies requiring further research are discussed in the following section.

Further Research

The aim of this chapter has been to identify the incidence, distribution and risk factors of sailing injuries. The scarcity of analytical studies, especially of Olympic-class sailing, is of concern. Little has changed in the past decade, since Allen (1999) called for sports medicine clinicians to collect injury data from Olympic sailors. In fact, to date, there have been no prospective analytical studies published in the English language literature on competitive Olympic-class sailing injuries.

This review of the sailing injury literature underscores the necessity for injury surveillance at all levels, from junior through to the elite Olympic classes. In particular, prospective data collection is required, in which the diagnosis of injury is confirmed by sports medicine clinicians rather than by the athlete or coach. A major issue highlighted by this review is the variation in methods and definition of injury used by studies.

Neville et al. (2006) used an injury definition similar to that adopted by other professional sports—"any incident occurring as a direct result of scheduled sailing or training causing pain, disability or tissue damage, resulting in at least one treatment from a medical officer"—thereby precluding minor ailments, medical advice, consultations, soft-tissue massage, and nonspecific treatments that did not meet this criterion.

Sailing-injury surveillance should avoid incorporating mixed definitions of injury; hence, a sailing injury should be defined as either a "medical attention injury," requiring medical attention from a qualified medical practitioner, or a "time-loss injury," resulting in a specified number of days' absence from sailing participation. Severity statistics should be included when possible to identify the injuries at greatest risk of affecting performance, participation, or health (van Mechelen 1997). Moreover, an understanding of the severity of injuries can enable prudent distribution of preventive resources.

With the notable risk of overuse injuries in sailing, consensus as to the definition of acute and chronic injuries is also required. In the classification of sprains and strains, the nature of injury should be based on the inciting events, regardless of the type of injury. For example, an acute injury should be defined as an injury resulting from a specific, single traumatic event, whereas a chronic injury should be defined as resulting from a gradual development of symptoms through overuse or prolonged exposure (Peterson & Renstrom 2001).

The risk of injury in sailing is largely unknown, as only one prospective study to date has included exposure data (Neville et al. 2006). Researchers are therefore encouraged to accurately collect exposure data so as to determine the actual risk and incidence of injury (Knowles et al. 2006). Sailing exposure should be reported as the total number of hours of sailing, from when the first sail is hoisted until when the last sail is dropped.

A number of questions have been highlighted by this literature review, which may help to direct future research:

- What are the distribution, incidence, and severity (in terms of time loss) of injuries in Olympic-class sailing?
- What, if any, are the differences in rates and characteristics of injuries between the Olympic classes?
- Are there differences in the incidence and nature of training and competition injuries?
- What are the long-term health effects of sailing injuries? In particular, is there any evidence of chronic lumbar spine degeneration as a result of sailing activities?
- What are the risks and nature of injuries in junior sailors?
- Do psychological stress, personality, and attitude (Halliwell 1989; May 2000) influence sailing injury during repeated races or regatta formats?

- Do body composition and somatotype (which are specific to the class and position of the athlete (Legg et al. 1997a; Bojsen-Moller et al. 2007; Shephard 1990) correlate to injury risk?
- Is there any evidence of hyperthermia, hypothermia, or dehydration affecting performance and injury rates in sailing?
- Do strength, fitness, flexibility, or muscle imbalances influence injury, in particular, hamstring: quadriceps strength ratio deficit (Bojsen-Moller et al. 2007), weak abdominal muscles and shortened hip flexor muscles (Blackburn 1994), posterior:anterior shoulder strength imbalance (Kibler & Garrett 1997; Neville et al. 2003, 2006)?
- Is there any evidence of intrinsic injury-prevention strategies reducing the risk of injuries? With particular reference to the following:
    - the position of the feet during hiking (Cockerill 1999)
    - the frequency and amplitude of pumping in windsurfing (Guevel, Hogrel & Marini 2000)
    - the contribution of the lower-limbs for force generation during grinding (Neville et al. 2003; Molloy et al. 2005)
    - the dynamic use of the whole body when off-shore steering (Spalding et al. 2005)
    - adopting a supinated hand-grip position on the boom to relieve forearm neuropathy syndromes in windsurfing (Ciniglio et al. 1990)
    - increasing the resilience of high-risk body regions through specific strength training (Zelhof 1990), prime examples are: the forearms of grinders and off-shore racing helmsmen, the shoulders of Olympic-class and big-boat sailors, the knees of hiking sailors and the lower back and abdominals of all sailors (Rovere 1987; Blackburn 1994).
    - monitoring sailing volume and intensity in managing recovery (Neville et al. 2008).
    - the role of nutrition and hydration in preventing fatigue and dehydration (Burke 2003; Slater & Tan 2007; Tan & Sunarja 2007; Neville, Gant & Folland 2009).
- Is there any evidence of extrinsic injury-prevention factors reducing the risk of injuries? With particular reference to the following:
    - protective clothing, such as helmets, gloves, shoes or booties (McCormick & Davis 1988; Dyson et al. 2006).
    - effective mechanism of foot-strap release (Dyson et al. 2006)
    - smaller boom grip size for female windsurfers (Allen & Locke 1989)
    - windsurfing harness with a quick-release system and a polychloroprene lower back brace to provide additional trunk support (Dyson et al. 2006)
    - improved design and friction on the grip of off-shore steering wheels (Spalding et al. 2005)
    - improved ergonomics below deck on off-shore racing yachts (Spalding et al. 2005)
    - higher grinding pedestals to reduce the degree of lumbar flexion (Allen 1999; Neville et al. 2006; Neville Pain & Folland 2009).

  The success of injury prevention in sports is largely due to the level of support given to the athlete, which includes coaching, sports science, medical, psychological, and social support. Multidisciplinary support staff structures are common in professional sailing teams (Neville et al. 2006); however, sailors at all levels would benefit from the support of informed personnel in the prevention of injuries (Allen & De Jong 2006). A greater amount of medical support should be directed toward injury prevention and not limited to the treatment of acute trauma.

In conclusion, sailors of all classes of sailing and level of ability seem to be at risk of injury, and thus to maximize the enjoyment and competitive level of the sport, there is an irrefutable need for informative scientific research of sailing injuries and injury-prevention strategies. Successful research requires a multidisciplinary team including coaches, sports scientists, and sports physicians, as well as the athletes. The research process should be driven by ISAF, the National Governing Bodies of sailing, as well as local yacht clubs, parents, and the athletes. Only through increasing our knowledge of the sport will athletes be free to achieve their quest for sailing enjoyment and success.

References

Allen, A. (2005) Sports medicine injuries in the America's Cup 2000. *New Zealand Journal of Sports Medicine* **33**(2), 43–47.

Allen, G.D. & Locke, S. (1989) Training activities, competitive histories and injury profiles of elite boardsailing athletes. *Australian Journal of Science & Medicine in Sport* **21**(2), 12–14.

Allen, J.B. (1999) Sports medicine and sailing. *Physical Medicine and Rehabilitation Clinics of North America* **10**(1), 49–65.

Allen, J.B. & De Jong, M.R. (2006) Sailing and sports medicine: a literature review. *British journal of sports medicine* **40**(7), 587–593.

Bernardi, M., Quattrini, F.M., Rodio, A., Fontana, G., Madaffari, A., Brugnoli, M. & Marchetti, M. (2007) Physiological characteristics of America's Cup sailors. *Journal of Sports Sciences* **25**(10), 1141–1152.

Blackburn, M. (1994) The stayed back: ideas and exercises to avoid problems with the sailing spine. *Australian Sailing*, 43–45, 67.

Bojsen-Moller, J., Larsson, B., Magnusson, S.P. & Aagaard, P. (2007) Yacht type and crew-specific differences in anthropometric, aerobic capacity, and muscle strength parameters among international Olympic class sailors. *Journal of Sports Science*, **25** (10), 1117–1128.

Bono, C.M. (2004) Low-back pain in athletes. *Journal of Bone and Joint Surgery, American* **86**(2), 382–396.

Bugge, M. (1986) The Third Whitbread Round the World Race. *Injury* **17**(3), 196–198.

Burke, L.M. (2003) Nutrition for open water sailing: an interview with Jeni Pearce, sports dietitian. *International Journal of Sport Nutrition and Exercise Metabolism* **13**(2), 244–249.

Ciniglio, M., Maffulli, N. & Del Torto, M. (1990) Transitory compression of the posterior interosseous nerve in windsurfers: a clinical and anatomical study. *Annals of sports medicine* **5**, 2, 81–84.

Cockerill, S. (1999) No pain: how to develop a hiking style that avoids the knee problems which put many out of the sport. *Australian Sailing*, 40–42.

Cockerill, S. & Taylor, F. (1998) Hitch-hikers guide: ways we can improve our hiking-out style and AVOID injury. *Yachts & Yachting*, **1353,** 11–15.

Crafer, S. (2004) Stretching for success: part 2. *Australian Sailing*, 42–45.

Cunningham, P. & Hale, T. (2007) Physiological responses of elite Laser sailors to 30 minutes of simulated upwind sailing. *Journal of Sports Sciences* **25**(10), 1109–1116.

Dyson, R.J., Buchanan, M., Farrington, T.A. & Hurrion, P.D. (1996) Electromyographic activity during windsurfing on water. *Journal of Sports Sciences* **14**(2), 125–130.

Dyson, R., Buchanan, M. & Hale, T. (2006) Incidence of sports injuries in elite competitive and recreational windsurfers. *British Journal of Sports Medicine* **40**(4), 346–350.

Guevel, A., Hogrel, J.Y. & Marini, J.F. (2000) Fatigue of elbow flexors during repeated flexion-extension cycles: effect of movement strategy. *International Journal of Sports Medicine* **21**(7), 492–498.

Halliwell, W. (1989) Delivering sport psychology services to the Canadian sailing team at the 1988 Summer Olympic Games. *Sport Psychologist* **3**(4), 313–319.

Jablecki, C.K. (1999) Lateral antebrachial cutaneous neuropathy in a windsurfer. *Muscle & Nerve* **22**, 7, 944–945.

Kibler, W.B. & Garrett, W.E., Jr. (1997) Pathophysiologic alterations in shoulder injury. *Instructional Course Lectures* **46**, 3–6.

Knowles, S.B., Marshall, S.W. & Guskiewicz, K.M. (2006) Issues in estimating risks and rates in sports injury research. *Journal of Athletic Training* **41**, 2.

Legg, S.J., Miller, A.B., Slyfield, D., Smith, P., Gilberd, C., Wilcox, H. & Tate, C. (1997a) Physical performance of elite New Zealand Olympic class sailors. *Journal of Sports Medicine and Physical Fitness* **37**, 1, 41–9.

Legg, S.J., Smith, P., Slyfield, D., Miller, A.B., Wilcox, H. & Gilberd, C. (1997b) Knowledge and reported use of sport science by elite New Zealand Olympic class sailors. *Journal of Sports Medicine and Physical Fitness* **37**(3), 213–217.

LifesavingSociety. (2003) *Canadian National Boating Fatalities Report*, The Lifesaving Society, Ontario, USA. May 2003.

Locke, S. & Allen, G.D. (1992) Etiology of low back pain in elite boardsailors. *Medicine and Science in Sports and Exercise* **24**(9), 964–966.

Mackie, H., Sanders, R. & Legg, S. (1999) The physical demands of Olympic yacht racing. *Journal of Science and Medicine in Sport/Sports Medicine Australia* **2**(4), 375–388.

Mackie, H.W. & Legg, S.J. (1999) Preliminary assessment of force demands in laser racing. *Journal of Science and Medicine in Sport/Sports Medicine Australia* **2**(1), 78–85.

May, J. (2000) Stressed out of the fleet: how to reduce stress on the racecourse. *Sailing World* **37**(7, 60–61.

McCormick, D.P. & Davis, A.L. (1988) Injuries in sailboard enthusiasts. *British Journal of Sports Medicine* **22**(3), 95–97.

Miller, C. (1987) Treating the America's Cup sailors. *Physician & Sportsmedicine* **15**(1), 172–176, 178.

Molloy, J., Neville, V.J., Wood, I. & Speedy, D. (2005) Posterior interosseous nerve entrapment. *New Zealand Journal of Sports Medicine* **33**(2), 48–51.

Moraes, J., Nery, C., Fontel, E., Morais, E., Cosendey, F., Rossatto, S. & Cosendey, A. (2003) Multidisciplinary assessment of the Brazilian Olympic sailing team. In: *Human Performance in Sailing Conference Proceedings: Incorporating the 4th European Conference on Sailing Sports Science and Sports Medicine and the 3rd Australian Sailing Science Conference* (Legg, S.J., Mackie, H. & Cochrane, D., eds.), Massey University, Auckland, New Zealand.

Nathanson, A., Fisher, G., Wallace, R., Baird, J. & Mello, M. (2006) *Sailing Injury and Safety Survey.* Brown University, in conjunction with the Injury Prevention Centre, Providence, RI.

Nathanson, A.T. & Reinert, S.E. (1999) Windsurfing injuries: results of a paper- and Internet-based survey. *Wilderness & Environmental Medicine* **10**(4), 218–225.

Neville, V., Gant, N. & Folland, J.P. (2009) Thermoregulatory demands of elite professional America's Cup yacht racing. *Scandinavian Journal of Medicine & Science in Sports* (in press).

Neville, V., Pain, M.T.G. & Folland, J.P. (2009) Aerobic power and peak power of elite America's Cup sailors. European *Journal of Applied Physiology* **106**, 149–157.

Neville, V., Gleeson, M. & Folland, J.P. (2008) Salivary IgA as a risk factor for upper respiratory infection in elite professional athletes. *Medicine and Science in Sports and Exercise* **40**(7), 1228–1236.

Neville, V., Molloy, J., Wood, I. & Speedy, D. (2003) The pain of PIN (abstract). In: *Human performance in sailing conference proceedings: incorporating the 4th European Conference on Sailing Sports Science and Sports Medicine and the 3rd Australian Sailing Science Conference, 9–10 January 2003* (Legg, S.J., ed.), Massey University, Auckland, New Zealand.

Neville, V.J., Molloy, J., Brooks, J.H., Speedy, D.B. & Atkinson, G. (2006) Epidemiology of injuries and illnesses in America's Cup yacht racing. *British Journal of Sports Medicine* **40**(4), 304–312.

Newton, F. (1989) Dinghy sailing. *The Practitioner* **233**(1472), 1032, 1035.

O'Connor, P. (2008) National assessment of boating fatalities in Australia 1999–2004, National Marine Safety Committee Inc., New South Wales, Australia May 2008. ISBN 0 642 7365 10.

Peterson, L. & Renstrom, P. (2001) *Sports Injuries: Their Prevention and Treatment*, 3rd ed., Human Kinetics, Champaign, IL.

Price, C.J., Spalding, T.J. & McKenzie, C. (2002) Patterns of illness and injury encountered in amateur ocean yacht racing: an analysis of the British Telecom Round the World Yacht Race 1996-1997. *British Journal of Sports Medicine* **36**(6), 457–462.

Rosenbaum, D.A. & Dietz, T.E. (2002) Windsurfing injuries: added awareness for diagnosis, treatment, and prevention. *Physician and Sportsmedicine* **30**(5), 15–16, 21–22, 24.

Rovere, G.D. (1987) Low back pain in athletes. *Physician and Sportsmedicine* **15**(1), 105–106, 115, 117.

Schaefer, O. (2000) Injuries in dinghy-sailing—an analysis of accidents among beginners. *Sportverletz Sportschaden* **14**(1), 25–30.

Scott, M. (2001) The fitness factor: part 2: Dinghy sailing strength and condition. *Yachts & Yachting*, **1430,** 58–64.

Shephard, R.J. (1990) The biology and medicine of sailing. *Sports Medicine (Auckland, N.Z.)* **9**(2), 86–99.

Shephard, R.J. (1997) Biology and medicine of sailing. An update. *Sports Medicine (Auckland, N.Z.)* **23**(6), 350–356.

Slater, G. & Tan, B. (2007) Body mass changes and nutrient intake of dinghy sailors while racing. *Journal of Sports Sciences* **25**(10), 1129–1135.

Spalding, T.J., Malinen, T., Tomson, M., Goertzen, M., Sinclair, R. & Allen, A. (2005) Analysis of medical problems during the 2001-2002 Volvo Ocean Race. *New Zealand Journal of Sports Medicine* **33**(2), 38–42.

Tan, B. & Sunarja, F. (2007) Body mass changes and nutrient intake of Optimist class sailors on a race day. *Journal of Sports Sciences* **25**(10), 1137–1140.

Thorn, J. (2007) Laser 4000 fatality. The Royal Yachting Association, Southampton, UK. October 2007, 16.

Ullis, K.C. & Anno, K. (1984) Injuries of competitive board sailors. *Physician and Sportsmedicine* **12**(6), 86–93.

van Mechelen, W. (1997) The severity of sports injuries. *Sports Medicine (Auckland, N.Z.)* **24**(3), 176–180.

van Mechelen, W., Hlobil, H. & Kemper, H.C. (1992) Incidence, severity, aetiology and prevention of sports injuries: a review of concepts. *Sports Medicine (Auckland, N.Z.)* **14**(2), 82–99.

Vangelakoudi, A., Vogiatzis, I. & Geladas, N. (2007) Anaerobic capacity, isometric endurance, and Laser sailing performance. *Journal of Sports Sciences* **25**(10), 1095–1100.

Vogiatzis, I., Spurway, N.C., Wilson, J. & Boreham, C. (1995) Assessment of aerobic and anaerobic demands of dinghy sailing at different wind velocities. *Journal of Sports Medicine and Physical Fitness* **35**(2), 103–107.

Whiting, P. (2007). *The 32nd America's Cup: A Simple Guide*, Wiley, New York.

Zelhof, R. (1990) The power to hike and trim: six exercises to improve sailing strength in one-design sailboats. *Sailing World* **29**(5), SM7–SM9.

Chapter 17

Soccer (Football)

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Introduction

Soccer is the world's most popular organized sport, with an estimated 265 million players (90% male, 10% female) participating worldwide in 2006 (FIFA 2007). This is an overall 10% increase in participation since 2000, with the greatest increases in participation in youth (32%) and girls (19%) over 6 years of age (FIFA 2007). In some countries, such as Canada, the increase in soccer participation over 20 years of age has been as much as 300% (Canadian Soccer Association 2007).

The game of soccer evolved during the late 19th century in England from a variety of ball games involving both handling and kicking the ball. In 1863, the London Football Association officially split the game of football into rugby football, in which handling and carrying the ball was allowed, and association football, which banned the use of the hands. The Football Association established the first set of official rules for soccer (FIFA 2008b). In 1888, 12 clubs from England founded the Football League, the first professional league competition (FIFA 2008b). In 1904, with representation from seven European soccer associations (France, Belgium, Denmark, the Netherlands, Spain, Sweden, and Switzerland), a governing body for the sport was organized in Paris, called the Fédération Internationale de Football Association (FIFA). Now FIFA is the world governing body for soccer and includes 208 national associations (FIFA 2008a).

Soccer was introduced as an exhibition sport and the first team sport included in the Olympic Games sport in 1900 and 1904 respectively (IOC 2008). Since 1908, soccer has been played in every summer Olympic Games. By the 1920s, however, professional leagues had evolved so that the Olympic Games, then restricted to amateur athletes, no longer represented the highest level of competition in the world (FIFA 2008a). The first FIFA World Cup was held in Uruguay in 1930 and is held every 4 years (FIFA 2008a).

Participants in organized soccer cross all age groups, levels of play from recreational to professional, ethnicities, and socioeconomic levels. Soccer is a sport that requires little equipment and offers numerous potential benefits related to physical-activity participation and resultant health outcomes, both physical and psychosocial. Soccer is, however, a collision/contact sport, and its participants are susceptible to the risk of injury. The incidence of injury in soccer is high, with reported rates of 10 to 35 injuries per 1,000 game-hours in adult men's soccer (Dvorak & Junge 2000) and 10–70 injuries per 1000 game hours in adult women's soccer (Steffen 2008). Consistently, lower extremity injuries account for the majority of injuries in soccer at all levels (>80%).

Soccer injuries may significantly impact quality of life. Reduction of soccer injury would have a major impact on quality of life through the maintenance and promotion of active living. For example, it is estimated that 8% of youths drop out of sport and recreational activities because of injury

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(Grimmer et al. 2000). There is epidemiologic evidence that level of physical fitness is a significant predictor of all-cause mortality, morbidity, and disease-specific morbidity (Blair 1993; Blair et al. 1995; Jebb & Moore 1999; Paffenbarger et al. 1994) and that physical-activity patterns track from early to later life (Must et al. 1992; Nieto et al. 1993). The prospect of injury or incomplete recovery from injury affects the ability to participate in sport and recreational activities that would be beneficial to health. Injuries have also been documented to be a leading cause of the development of osteoarthritis in later life (Roos et al. 1998; Drawer & Fuller 2001; Englund et al. 2003; Lohmander 2004; von Prat et al. 2004; Koh & Dietz 2005; Myklebust & Bahr 2005; Roos 2005). There is a significant public health cost associated with these injuries, the future development of osteoarthritis, and other diseases associated with decreased levels of physical activity (Angus et al. 1998).

There are previous comprehensive reviews of the literature examining the epidemiology of injuries in soccer. Inklaar (1994a, 1994b) concluded that the epidemiologic evidence regarding soccer injury is inconsistent and far from complete. Larsen et al. (1996) also concluded that the evidence reported was inconsistent because of inconsistencies in injury definitions and surveillance methods. Olsen et al. (2004) examined strategies for prevention of soccer injuries and concluded that while some strategies to prevent injuries in elite soccer look promising, weak research design has led to inadequate evaluation. Steffen (2008) has examined the epidemiology of injury in women's soccer and concluded that there are few prospective studies examining risk factors, mechanisms of injury, and prevention strategies for injury. In addition, she suggested that a multivariate approach to risk was rarely examined. Despite the significant contribution of these epidemiologic reviews of the literature, a comprehensive review of the literature has not been completed examining all aspects of epidemiology of injury in soccer in the past 10 years.

As such, the purpose of this chapter is to examine the epidemiology of injury in competitive adult levels of soccer. The focus will remain on outdoor soccer, which is played in the Olympic Games. This comprehensive review of the literature will examine injury incidence, descriptive epidemiology, mechanisms of injury, outcomes of injury, risk factors for injury, and injury-prevention strategies in competitive soccer. This review will include a summary of recommendations for future research examining risk factors and prevention strategies for injury in soccer. These recommendations will include methodologic considerations for future research.

The most challenging element in comparing research in this area is the inconsistency in injury definitions and injury-severity definitions. A methodologic consensus statement was published in 2006 to identify definitions and methods to ensure consistency and comparability of results in studies examining injury in soccer (Fuller et al. 2006). For the purpose of this review, a consensus statement on injury definitions and data-collection procedures in studies of soccer injuries will be considered in the evaluation of the epidemiologic literature reviewed (Fuller et al. 2006). To facilitate comparisons between studies, an attempt will be made to use the proposed definitions based on this consensus statement when possible. As such, an injury will be defined as any physical symptom sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time lost from football. An injury that results in a player receiving medical attention by a qualified medical practitioner is referred to as a "medical-attention" injury. An injury that results from a player being unable to take full part in future football training or match play is referred to as a "time-loss" injury.

Who Is Affected by Injury?

The estimated 265 million players participating in soccer worldwide in 2006 (FIFA 2007) represent players from recreational through elite and international professional players. Organized soccer begins as young as age 3 in some countries. Few data exist on injury for this very young age group; however, with soccer participation comes the potential for soccer injury. Soccer injuries can occur in any participant, regardless of age, sex, or level of play. The overall rates of injury by sex, age group, regular

Table 17.1 Incidence of injury in elite male, female, and tournament soccer players.

Study	Study Design (country, yr)	Population (sex, age, level of play, other)	Sample Size or Denominator Data	Injury Definition
Adult Male				
Agel et al. (2007)	Descriptive (USA, 1988–2003)	Male college (NCAA) 15 yr	>22,000 G and >62,000 P	Medical attention (physician or certified athletic trainer) and time loss or restricted performance ⩾1 day + any dental injury
Albert (1983)	Descriptive (USA, 1979–1981)	Male professional (ages 19–38) 3 outdoor seasons	56 players	Medical attention (physician) or time loss
Arnason (1996)	Cohort (Iceland, 1991)	Men's elite (ages 18–34) 1 season	84 players	Time loss
Drawer & Fuller (2002)	Cohort (Britain, 1994–1997)	Male professional 2.5 yr	87,529 player-hr	Time loss
Engstrom et al. (1990)	Cohort (Sweden)	Male (elite) 1 season	64	Time loss
Hawkins et al. (2001)	Cohort (Britain, 1997–1999)	Male (91 professional football clubs) 2 yr	n = 2,376	Time loss >2 days
Hagglund et al. (2006)	Cohort (Sweden, 2001–2002)	Male (ages 17–38, top elite divisions) 1 year	n = 525	Time loss
Inklaar et al. (1996)	Cohort (The Netherlands 1986–1987)	Adult + youth (male, elite amateur, ages 13–60) 1 season	n = 477 (adult = 245, youth = 232)	Time loss
Luthje et al. (1996)	Cohort (Finland, 1993)	Adult (male, elite, ages 17–35) 1 season	n = 263	Medical attention
Nielsen et al. (1989)	Cohort (Denmark)	Youth + adult (male, ages 16–adult. Club soccer various levels) 1 season	Adult, 93 Youth, 30	Time loss
Peterson et al. (2000)	Cohort (Switzerland)	Adult + youth (age groups: adult, 16–18, 14–16; all levels: high through low) 1 yr	n = 264	All
Poulsen et al. (1991)	Cohort (Denmark 1986)	Adult (male, 21–30, varying levels) 1 yr	n = 55	Time loss
Walden et al. (2005)	Cohort (Europe, 2001–2002)	Professional (male; mean age, 26) 1 season	n = 266	Time loss

Data-Collection Method	No. of Injuries	Game Incidence Rate (95% CI) [no. of injuries per 1,000 hr unless specified AEs]	Practice Incidence Rate (95% CI) [no. of injuries per 1,000 hr or AEs]	Total Incidence Rate (95% CI) [no. of injuries per 1,000 hr or AEs]
Injury surveillance system (athletic trainer)	G = 6,693 P = 6,281	18.75 (18.3 –19.2) [AE]	4.34 (4.24–4.45) [AE]	
Injury surveillance system (athletic trainer)	Outdoor = 106			1981 outdoor season 10.1 (6.48–14.99) [AE]
Injury surveillance (physical therapist, physician or coach)	85	34.8	5.9	
Injury surveillance (club senior physiotherapist)	744			8.5
Injury surveillance (athletic trainer)	85	24	7	
Injury surveillance (team medical practitioner)	6,030	25.9	3.4	
Injury surveillance (physician or physical therapist)	1,189	(2001) 25.9 (22.8–29.2) (2002) 22.7 (20.0–25.8)	(2001) 5.1 (4.6–5.6) (2002) 5.3 (4.7–5.8)	(2001) 7.6 (7.1–8.3) (2002) 7.6 (7.0–8.3)
Interview	83			13–14 yr, 12.8 15–16 yr, 16.1 17–18 yr, 28.3 Adult, 15.8
Injury surveillance (physician)	236 (outdoor only)	16.6	1.5	
Injury surveillance (physician)	Adult 82	High-level adult, 18.4 Lower-level adult, 11.9	High-level adult, 2.3 Lower-level adult, 5.6	
Injury surveillance (physician)	558	Adult high to low level, range: 18.6–29.3	Adult high to low level, range: 6.5–28.5	Adult high to low level, range: 18.6–29.3
Interview biweekly (study physician)	56	Highest division, 19.76 Middle divisions, 20.69	Highest division, 4.07 Middle divisions, 5.69	
Injury surveillance (physician)	658	30.5 (23.1–37.9)	5.8 (3.6–6.4)	9.4 (7.3–11.5)

(*continued*)

Table 17.1 (*continued*)

Study	Study Design (country, yr)	Population (sex, age, level of play, other)	Sample Size or Denominator Data	Injury Definition
Adult Female				
Dick et al. (2007)	Descriptive (USA, 1988–2003)	Women's college (NCAA) 15 yr	20,447 G and 54,750 P	Medical attention (physician or certified athletic trainer) and time loss or restricted performance ⩾1 day + any dental injury (1994 onward)
Engstrom et al. (1991)	Cohort (Sweden)	Female (age 21 yr, elite) 1 yr	n = 41	Time loss
Faude et al. (2005)	Cohort (Germany, 2003–2004)	Female (ages 17–27, elite, national league) 11 mo	n = 165	Time loss
Giza et al. (2005)	Cohort (USA 2001–2003)	Female (age not reported, elite) 2 × 5 mo	n = 202	Time loss
Jacobson & Tegner (2007)	Cohort (Sweden, 2000)	Female (ages 16–36, premiere league) 10 mo	n = 269	Time loss
Ostenberg & Roos (2000)	Cohort (Sweden, 1996)	Female (ages 14–39) 7 mo	n = 123	Time loss
Soderman et al. (2001)	Cohort (Sweden, 1998)	Female (ages 20–25, elite) 7 mo	n = 146	Time loss
Tournament				
Dvorak et al. (2007a)	Cohort (Germany, 2006)	Male (FIFA World Cup, tournament)	2111 tournament player hours	Medical attention (team physician)
Junge (2004c)	Cohort (international, 1998–2001)	Male + female tournament (12 international)	10,155 player-hr	Medical attention + time loss
Junge (2004b)	Cohort (international, 2002)	Male (international tournament)	2,111 player-hr	Medical attention
Junge et al. (2006)	Cohort (international, 2004)	Male and female Olympic Games		Medical attention
Junge & Dvorak (2007)	Cohort (international, 1999–2006)	Female tournament (7 international)	5742 player-hr	Medical attention
Walden et al. (2007)	Cohort (Europe, 2004–2005)	MS Championship, WS Championship, MU Championship	MS = 368 WS = 160 MU 144	Medical attention

AE = athlete-exposure; G = player-games; MS = Men's Senior; MU = Men's U-19; P = player-practices; WS = Women's Senior.

Data-Collection Method	No. of Injuries	Game Incidence Rate (95% CI) [no. of injuries per 1,000 hr unless specified AEs]	Practice Incidence Rate (95% CI) [no. of injuries per 1,000 hr or AEs]	Total Incidence Rate (95% CI) [no. of injuries per 1,000 hr or AEs]
Injury surveillance system (athletic trainer)	G = 5,373 P = 5,836	16.44 (16.0 –16.88) [AE]	5.23 (5.09–5.36) [AE]	
Injury surveillance system (medical student)	78	24	7	
Injury surveillance system (physical therapist, physician)	241	23.3	2.8	6.8
Injury surveillance system (physician)	173	12.6	1.2	1.9
Interview by primary investigator weekly	237	13.9	2.7	4.6
Injury surveillance system (physical therapist)	65	14.3	3.7	6.6
Injury surveillance system (physical therapist)	80	Acute. 10.0	Acute. 1.3	Acute. 5.5
Injury surveillance (team physician)	145	68.7 (57.5–79.9)		
Injury surveillance (physician)	901	All, 88.7 Time loss, 35 Men, 53–191 Women, 39–64		
Injury surveillance (physician)	171	81.0		
Injury surveillance (physician)	Men, 77 Women, 45	Men, 73 (57–89) Women, 70 (50–90)		
Injury surveillance (physician)	387	67.4 (60.7–74.1)		
Injury surveillance (physician)	MS, 40 WS, 17 MU, 16	MS, 36.0 WS, 36.0 MU, 30.4	MS, 2.1 WS, 2.5 MU, 2.9	

Figure 17.1 Women's elite soccer is gaining in popularity. © IOC / Steve MUNDAY.

season and tournament play, session type (i.e., practice, game) are summarized in Table 17.1. Only studies reporting injury rates per 1000 player-hours or 1000 athlete exposures are reported. In addition, studies relying solely on self report have not been included. Only studies in which a method of injury surveillance is in place are reported. In addition, only studies which identify injuries as "time loss" or "medical attention" injuries as per consensus definition will be included (Fuller et al. 2006).

The reported incidence of injury in elite amateur (including college) and professional men's soccer ranges from 17 to 35 injuries per 1,000 player-hours in regular season game play and 2 to 7 in regular season practice (Nielsen et al. 1989; Engstrom et al. 1990; Poulsen et al. 1991; Arnason 1996; Luthje et al. 1996; Peterson et al. 2000; Hawkins, Hulse & Wilkinson 2001; Hagglund et al. 2006; Walden et al. 2005; Agel et al. 2007). In elite amateur (including college) women's soccer (Figure 17.1) the reported incidence of injury ranges from 13 to 24 injuries per 1,000 player-hours in regular season game play and 1 to 7 in regular season practice (Engstrom et al. 1991; Faude et al. 2005; Giza et al. 20052007; Ostenberg & Roos 2000; Soderman et al. 2001; Dick et al. 2007; Jacobson & Tegner). Overall, the reported rates of injury in regular-season game play are slightly lower in elite women's competition as compared with men's competition. In practice (training) the rates of injury reported are similar for men and women. In men's elite tournament play, the injury rates reported range from 36 to 89 injuries per 1,000 player-hours (Junge 2004b,c; Junge et al. 2006; Walden et al. 2007). In women's elite tournament play, the reported injury rates range from 36 to 70 injuries per 1,000 player-hours (Junge, 2004c, 2006; Walden et al. 2007). These data suggest that in tournament play, injury rates are higher than in regular season play for both men and women.

Where Does Injury Occur?

Anatomical Location

Lower-extremity injuries accounted for 67% to 88% of all injuries reported in men's and women's soccer, regardless of whether it was regular-season or tournament play (Table 17.2). Upper-extremity injuries, on the other hand, accounted for only 2% to 15% of all injuries in all age groups in both men's and women's leagues. Consistently, the most frequently injured body parts were the ankle, knee, and thigh across all age groups and both sexes (Table 17.2). By sex, it appears that in elite women's regular season play, the proportion of total injuries accounted for by knee injuries typically exceeds that of groin and thigh injuries (Engstrom et al. 1991; Ostenburg & Roos 2000; Soderman et al. 2001; Giza et al. 2005), whereas the opposite is true for male elite players (Albert 1983; Poulsen et al. 1991; Luthje et al. 1996; Peterson et al. 2000; Drawer & Fuller 2002; Walden et al. 2005; Haglund et al. 2006). The same is true for elite men's tournament play (Junge et al. 2004b; Dvorak et al. 2007; Walden et al. 2007); however, in elite women's tournament play, groin and thigh injuries appear to account for a similar proportion of injuries as knee injuries (Junge 2006, 2007).

Head and neck injuries accounted for 3% to 18% of all injuries in elite men's soccer (Albert 1983; Luthje et al. 1996; Peterson et al. 2000; Hawkins et al. 2001; Walden et al. 2005; Hagglund et al. 2006; Agel et al. 2007) and 7% to 18% in elite women's soccer (Faude et al. 2005, Giza et al. 2005, Dick et al. 2007; Jacobson & Tegner 2007) during the regular season. In tournament play, head and neck injuries accounted for up to 21% and 33% in men and women, respectively (Maehlum et al. 1999; Junge et al. 2004c). Head and neck injury rates reported in men's and women's elite soccer were 1 to 1.8 injuries per 1,000 player-hours (Hawkins & Fuller 1999; Elias 2001; Faude et al. 2005; Agel et al. 2007; Dick et al. 2007). It should be noted, however, that concussion often goes unreported. Delaney et al. (2002) reported that while 63% of varsity soccer and football players reported signs and symptoms related to a concussion, only 20% realized that they had sustained a concussion.

Environmental Location

Overwhelmingly, the incidence of injury reported in soccer is clearly much higher during games than in practice at all levels of play (Table 17.1). The increased risk of injury in games as compared with training ranges from 3- to 1-fold in studies across both sexes and all age groups.

Some studies have examined the risk of injury on natural grass as compared with artificial turf. These findings will be discussed further, along with other risk factors, in the "What Are the Risk Factors" section.

When Does Injury Occur?

Injury Onset

Given the nature of the sport (i.e., speed, pivoting, jumping, collisions) it is not surprising that the majority of soccer injuries reported in relevant studies were acute in nature. In the studies that defined overuse injuries specifically, they were categorized as a pain syndrome of the musculoskeletal system with insidious onset and without any known trauma or disease that might have caused previous symptoms (Walden et al. 2005; Hagglund et al. 2007). In men's elite soccer, acute-onset injuries accounted for 63% to 94% of injuries (Arnason 1996; Luthje et al. 1996; Peterson et al. 2000; Walden et al. 2005; Hagglund et al. 2006). In women's elite soccer, acute-onset injuries accounted for 69% to 84% of injuries (Engstrom et al. 1991; Ostenberg & Roos 2000; Soderman et al. 2001; Faude et al. 2005; Giza et al. 2005; Jacobson & Tegner 2007).

Chronometry

Time in Game

Walden et al. (2007a) reported a significantly higher proportion of noncontact injuries in the second half of elite tournament play. Tscholl et al. (2007a), however, found no significant differences between the 1st and 2nd half of the game in elite tournament play; however, non-contact injury was not reported in this regard. Tscholl et al. (2007a) also reported a 2.5-fold increased risk of injury in the last 15 minutes of the second half of knock-out matches in tournament play. Junge & Dvorak 2007a did not find any difference in injury risk in the first as compared with the second half of elite women's tournament play; however, they did report fewer injuries in the first 15 minutes of play in both the first and second half of tournament games.

Time of Season

Agel et al. (2007) reported the greatest rates of injury across 15 years of men's collegiate soccer in the preseason as compared with the regular season (Incidence Rate Ratio, [IRR] 3.3; 95% confidence

Table 17.2 Anatomical location of injury (%) in elite male, female, and tournament soccer players.

Study	Study Design (country, yr)	Population (sex, age, level of play, other)	Sample Size or Denominator Data	Injury Definition
Adult Male				
Agel et al. (2007)	Descriptive (USA, 1988–2003)	Male college (NCAA) 15 yr	>22,000 G and >62,000 P	Medical attention (physician or athletic trainer) and time lost or restricted performance ⩾1 day + any dental injury
Albert (1983)	Descriptive (USA, 1979–1981)	Male Professional (ages 19–38) 3 outdoor seasons	56 players	Medical attention (physician) or time loss
Arnason (1996)	Cohort (Iceland, 1991)	Men's elite (ages 18–34) 1 season	84 players	Time loss
Drawer & Fuller (2002)	Cohort (Britain, 1994–1997)	Male Professional 2.5 yr	87,529 player-hr	Time loss
Hawkins et al. (2001)	Cohort (Britain, 1997–1999)	Male (91 professional football clubs) 2 yr	n = 2376	Time loss >2 days
Hagglund et al. (2006)	Cohort (Sweden, 2001–2002)	Male (ages 17–38, top elite divisions) 2 yr	n = 525	Time loss
Luthje et al. (1996)	Cohort (Finland, 1993)	Adult (male, elite, ages 17–35) 1 season	n = 263	Medical attention
Nielsen et al. (1989)	Cohort (Denmark)	Youth + adult (male, ages 16–adult. Club soccer various levels) 1 season	Adult = 93 Youth = 30	Time loss
Peterson et al. (2000)	Cohort (Switzerland)	Adult + Youth (age groups: adult, 16–18, 14–16, all levels: high through low) 1 yr	n = 264	All
Poulsen et al. (1991)	Cohort (Denmark 1986)	Adult (male, 21–30, varying levels) 1 yr	n = 55	Time loss
Walden et al. (2005)	Cohort (Europe, 2001–2002)	Professional (male, mean age 26) 1 season	n = 266	Time loss
Adult Female				
Dick et al. (2007)	Descriptive (USA, 1988–2003)	Women's college (NCAA) 15 yr	20,447 G and 54,750 P	Medical attention (physician or athletic trainer) and time lost or restricted performance ⩾1 day + any dental injury (1994 onward)
Engstrom et al. (1991)	Cohort (Sweden)	Female (21 yr, elite) 1 yr	n = 41	Time loss
Faude et al. (2005)	Cohort (Germany, 2003–2004)	Female (ages 17–27, elite, national league) 11 mo	n = 165	Time loss
Giza et al. (2005)	Cohort (USA 2001–2003)	Female (age not reported, elite) 2 × 5 mo	n = 202	Time loss
Jacobson & Tegner (2007)	Cohort (Sweden, 2000)	Female (ages 16–36, premiere league) 10 mo	n = 269	Time loss

Anatomical Injury Location (game/practice when known)									
Head/Neck	Trunk/Back	Upper Extremity	Hip/Groin	Thigh	Knee	Lower Leg	Ankle	Foot	Other
12.8/4.8	10.5/13.9	6.8/5.3	67.3/70.7 (all LE injury)	NA	NA	NA	NA	NA	2.6/5.3
8.5	7.6	5.7	10.4	21.7	17	4.7	24.5		
				16 hamstring			13 ankle sprain		
			10.8	22.2	15.2	13	16		
7 (+ spine)	2 (− spine)	3	12	23	17	12	17	6	20
2001/2002 3/3	7/9	2/2	7/9	23/22	15/18	16/10	10/9	7/8	
9	9	6	2	22	19	8	17	8	
			14.8		22.2		37	7.4	18.5
3.6 head	5.9 back	5.4	7.3 groin	14.5	17.7	9.5	20.4	10	5.6
			10.5	17.5	22.8	1.8	19.3	21.1	7
3	6		12	23	20	11	14	5.5	5.5
13.8/3.9	8.4/13.2	6.3/4.2	67.8/ 72 (all LE injury)	NA	NA	NA	NA	NA	3.7/6.7
	3.8		6.4	15.4	23	9	25.6	9	7.7
6.6	7.5	5.3	6.2	18.3	18.7	8.2	17.8	11.2	
10.4	12.8	7.5	5.5	6.9	31.8	6.5	9.3	9.3	
4.7	12.7	0.34	4.8	11.4	15.3	12.2	28.4	10.5	

(*continued*)

Table 17.2 (*continued*)

Study	Study Design (country, yr)	Population (sex, age, level of play, other)	Sample Size or Denominator Data	Injury Definition
Adult Female				
Ostenberg & Roos (2000)	Cohort (Sweden, 1996)	Female (ages 14-39) 7 months	n = 123	Time loss
Soderman et al. (2001)	Cohort (Sweden, 1998)	Female (ages 20–25, elite) 7 mo	n = 146	Time loss
Tournament				
Dvorak et al. (2007)	Cohort (Germany, 2006)	Male (FIFA World Cup, tournament)	2,111 tournament player-hr	Medical attention (team physician)
Junge et al. (2004c)	Cohort (International, 1998–2001)	Male + female tournament (12 international)	10,155 player hours	Medical attention + time loss
Junge (2004b)	Cohort (International, 2002)	Male (international tournament)	2,111 player hours	Medical attention
Junge et al. (2006)	Cohort (International, 2004)	Male and female Olympic Games		Medical attention
Junge & Dvorak (2007)	Cohort (International, 1999–2006)	Female tournament (7 international)	5,742 player-hr	Medical attention
Walden et al. (2007)	Cohort (Europe, 2004–2005)	MS Championship, WS Championship, MU Championship	MS = 368 WS = 160 MU = 144	Medical attention

AE = athlete-exposure; G = player-games; LE = xxxxx; MS = Men's Senior; MU = Men's U-19; NA= not available; P = player-practices;

interval [CI], 3.1–3.5) and in the regular season as compared with the postseason (Incidence Rate Ratio, [IRR] 1.3; 95% CI, 1.1–1.5)]. Dick et al. (2007) reported similar findings across 15 years of women's collegiate soccer, with the greatest rates of injury in the preseason as compared with the regular season (Incidence Rate Ratio, [IRR] 1.19; 95% CI, 1.04–1.36) and in the regular season as compared with the postseason (Incidence Rate Ratio, [IRR] 1.4; 95% CI, 1.22–1.65).

What Is the Outcome?

Injury Type

Studies examining injury type are summarized in Table 17.3. The most common injury types reported are muscle strains, ligament sprains and contusions. There is some indication that the greatest proportion of injuries was ligament sprain (33–66%) in most studies in women's soccer (Engstrom et al. 1991; Soderman et al. 2001; Faude et al. 2005; Junge et al. 2007). In other women's studies, muscle strains accounted for the greatest proportion of injuries (Ostenberg & Roos 2000; Giza et al. 2005; Jacobson & Tegner 2007,). In men's elite soccer, muscle strains accounted for the greatest proportion of injuries in the majority of studies (Albert 1983; Arnason 1996; Hawkins et al. 2001; Drawer & Fuller 2002; Walden et al. 2005; Hagglund et al. 2006; Dvorak et al. 2007). Contusions are consistently among the three most common injury types reported across both sexes. In tournament play, contusions accounted for the

Anatomical Injury Location (game/practice when known)									
Head/Neck	Trunk/Back	Upper Extremity	Hip/Groin	Thigh	Knee	Lower Leg	Ankle	Foot	Other
	10.8	7.7	17	26.2	6.2	10.8	12.3	9.2	
			3.3	16.4	24.6	4.9	45.9	4.9	
12 head	6.6	6.3	5.7	16.1	12.7	18.7	15.5	6.3	0.3
8–33	3–33	0–13		8–22	8–23	0–23	0–23		0–25
14.6 head	3.5	4.7	6.4	17.5	12.9	17	14.6	8.2	0.6
M/F 14/16	8/9	6/7	5/2	17/16	16/11	18/13	12/20	4/7	
18	9	8	3.1	12	11	11	24	3.1	
1.3	5	6.5	8.8	21.3	13.8	12.5	18.8	12.5	

WS = Women's Senior.

greatest proportion of injuries in the majority of studies across sex and age groups (Junge 2004b,c; Junge et al. 2006; Dvorak et al. 2007; Junge & Dvorak 2007). Fractures accounted for 1% to 12% of injuries in most studies (Albert 1983; Engstrom et al. 1991; Poulsen et al. 1991; Inklaar et al. 1996; Hawkins et al. 2001; Soderman et al. 2001; Drawer & Fuller 2002; Faude et al. 2005; Giza et al. 2005; Hagglund et al. 2006; LeGall et al. 2006; Walden et al. 2005; Jacobson & Tegner 2007). Concussions accounted for 2% to 7% of injuries (Albert 1983; Junge 2004b,c; Giza et al. 2005; Junge et al. 2006; Junge & Dvorak 2007; Jacobson & Tegner 2007).

By specific injury type, the most common injuries reported at all levels of play is ankle sprains, with reported rates of 1.5 to 3 injuries per 1,000 player-hours in men's, women's, and youth elite levels of play (Agel et al. 2007; Dick et al. 2007; Kofotolis et al. 2007).

Anterior cruciate ligament (ACL) injury has become one of the most significant concerns in elite levels of soccer because of the inability of some players to return to their preinjury level of participation, in addition to the long-term sequelae associated with osteoarthritis (Myklebust & Bahr 2005). ACL injury rates are reportedly 2 to 6 times higher in female as compared with male athletes (Bjordal & Arnoy 1997, Hewett et al. 2006, Griffin et al. 2005, Mihata et al. 2006). Injury rates estimated in women's and girl's soccer range from 0.07 to 0.5 injuries per 1,000 player-hours (Bjordal & Arnoy 1997; Faude et al. 2005; Giza et al. 2005; Mandelbaum et al.

Table 17.3 Injury type (%) in elite male, female, and tournament soccer players.

Study	Study Design (country, yr)	Population (sex, age, level of play, other)	Sample Size or Denominator Data
Adult Male			
Albert (1983)	Descriptive (USA, 1979–1981)	Male professional (ages 19–38) 3 outdoor seasons	56 players
Arnason (1996)	Cohort (Iceland, 1991)	Men's elite (ages 18–34) 1 season	84 players
Drawer & Fuller (2002)	Cohort (Britain, 1994–1997)	Male Professional 2.5 yr	87,529 player-hr
Hawkins et al. (2001)	Cohort (Britain, 1997–1999)	Male (91 professional football clubs) 2 yr	n = 2376
Hagglund et al. (2006)	Cohort (Sweden, 2001–2002)	Male (ages 17–38, top elite divisions) 2 yr	n = 525
Poulsen et al. (1991)	Cohort (Denmark 1986)	Adult (male, 21–30, varying levels) 1 yr	n = 55
Walden et al. (2005)	Cohort (Europe, 2001–2002)	Professional (male, mean age 26) 1 season	n = 266
Adult Female			
Engstrom et al. (1991)	Cohort (Sweden)	Female (21 yr, elite) 1 year	n = 41
Faude et al. (2005)	Cohort (Germany, 2003–2004)	Female (ages 17–27, elite, national league) 11 mo	n = 165
Giza et al. (2005)	Cohort (USA 2001–2003)	Female (age not reported, elite) 2 × 5 mo	n = 202
Jacobson & Tegner (2007)	Cohort (Sweden, 2000)	Female (ages 16–36, premiere league) 10 mo	n = 269
Ostenberg & Roos (2000)	Cohort (Sweden, 1996)	Female (ages 14–39) 7 mo	n = 123
Soderman et al. (2001)	Cohort (Sweden, 1998)	Female (ages 20–25, elite) 7 mo	n = 146
Tournament			
Dvorak et al. (2007)	Cohort (Germany, 2006)	Male (FIFA World Cup, tournament)	2,111 tournament player-hr
Junge (2007)	Cohort (international, 1999–2006)	Female tournament (7 international)	5,742 player-hr
Junge et al. (2004c)	Cohort (international, 1998–2001)	Male + female tournament (12 international)	10,155 player-hr
Junge (2004b)	Cohort (international, 2002)	Male (international tournament)	2,111 player hours
Junge et al. (2006)	Cohort (international, 2004)	Male and Female Olympic Games	

Injury Definition	Injury Type (game/practice when known)						
	Sprain	Strain	Contusion	Concussion	Fracture	Dislocation	Other
Medical attention (physician) or time loss	27.4	34	16	1.9	4.7	2.8	
Time loss	22	29	20				28
Time loss	19.3	40.6	19.8		3.8		
Time loss >2 days	19	37	13		4		
Time loss	2001/2002 15/17	23/19	15/15		3/3	<1/<1	5/6
Time loss	42.1	29.8	12.3		7	0	8.8
Time loss	21	26	16		2	1	
Time loss	33.3	10.3	15.3		1.2		15.3
Time loss	46.5	17.4	23.7		5.4		16.1
Time loss	19.1	30.7	16.2	2.9	11.6		
Time loss	24.5	28.7	8.4	3.8	1.3	0.8	1.7
Time loss	18.5	32.2	16.9		3.1		7.8
Time loss	65.6	16.4	18				
Medical attention (team physician)	14	15	51				
Medical attention	26	8	45	3.1	2.3	2.1	
Medical attention + time loss	5–24	3–25	35–76	0–7	0–10	0–3	
Medical attention	14	15	50	2.3	1.8		
Medical attention	M/F 9/29	6/9	71/36	0/4	1/2	0/4	

2005; Mihata et al. 2006; Ostenberg & Roos 2000; Steffen et al. 2008).

Time Loss

Based on the recent consensus statement on injury definitions and data-collection procedures in studies of soccer injuries, time-loss categories estimating severity of injury include slight (0 days), minimal (1–3), mild (4–7) , moderate (8–28), and severe (>28) if these are reported (Fuller et al. 2006). Proportion of injuries by time-loss categories are summarized in Table 17.4. The majority of injuries in men's, women's, and youth soccer are categorized as mild (4–7 days time loss) or moderate (8–28). Severe injuries (>28 days time loss) accounted for 10% to 25% of all injuries across sexes, youth, and tournament soccer.

Clinical Outcome

Many studies examining reinjury rates in either men's or women's soccer reported 20% to 46% of injuries as recurrent (Nielsen & Yde 1989; Inklaar 1994b; Arnason et al. 1996; Hagglund et al. 1996; Hawkins & Fuller 1999; Dvorak et al. 2000; Ostenberg & Roos 2000; Soderman et al. 2001; Faude et al. 2005; Walden et al. 2007) In soccer, there is a greater risk of injury reported for players with a history of injury in many prospective cohort studies. These results will be discussed further in the "What Are the Risk Factors" section.

Injuries have also been documented to be a leading cause of the development of osteoarthritis in later life. There is evidence that knee and ankle injuries, specifically, resulted in an increased risk of early development of osteoarthritis (Roos et al. 1998; Drawer & Fuller 2001; Englund et al. 2003; Lohmander 2004; von Prat et al. 2004; Koh & Dietz 2005; Myklebust & Bahr 2005; Roos 2005). Long-term follow-up studies provide evidence that 12 to 20 years after knee injury (meniscus and or ACL injury), >50% of those injured will have knee osteoarthritis, as comparison with 5% in the uninjured population (Myklebust & Bahr 2005; Roos 2005). Specifically, soccer players have been shown to have a higher incidence of ankle and knee arthritis than age-matched controls (Larsen, Jensen & Jensen 1999).

The National Centre for Catastrophic Sport Injury Research (2007) reported 16 direct catastrophic injuries between 1982 and 2007 in high-school and college soccer. A catastrophic injury directly resulting from participation in soccer was categorized as a fatality, a nonfatality (i.e., permanent severe functional disability), or serious (i.e., no permanent functional disability but severe injury such as a fractured cervical vertebrae with no paralysis).

Economic Cost

There is a significant public health cost associated with soccer injuries, the future development of osteoarthritis, and other diseases associated with decreased levels of physical activity (Angus et al. 1998). Dvorak & Junge 2000 suggested a conservative estimate of $150 for the primary medical costs associated with each soccer injury, suggesting $30 billion annually for primary medical costs for soccer injuries based on players in the United States actively registered with FIFA. One of the most costly injuries associated with soccer is likely ACL injury. In an economic evaluation of youth basketball injuries completed alongside a randomized, controlled trial (RCT) examining a prevention strategy for injury in youth basketball (Emery et al. 2007), McAllister (2007) estimated a range of direct health care costs (1-year time horizon) associated with ACL injury of $7,000 to $9,000 in 1994 Canadian dollars.

What Are The Risk Factors?

Causality associated with injury is both extremely complex and dynamic in nature. Meeuwisse (1994) initially developed a multifactorial model of causation that attempted to account for the interaction of multiple risk factors. Risk factors in soccer are any factors that may increase the potential for injury. Risk factors may be extrinsic (i.e., weather, field conditions) or intrinsic (i.e., age, conditioning) to the player. Modifiable risk factors refer to those that can be altered by injury-prevention strategies to reduce injury rates (Meeuwisse 1991; Emery 2003). Nonmodifiable risk factors, which cannot be altered, may affect the relationship between modifiable risk factors and injury.

Nonmodifiable Intrinsic Risk Factors

Previous Injury

Previous injury is the most consistently reported risk factor for injury in soccer and other sports (Emery 2003). It has been suggested that this may be a result of inadequate rehabilitation (Emery 2003). In soccer, there is a greater risk of injury reported for players with a history of injury in many prospective cohort studies. Hagglund et al. (2006) reported a greater risk of all injuries (hazard ratio, 2.7; 95% CI, 1.7–4.3). By specific injury type, Hagglund et al. (2006) found that players with a previous hamstring, groin, or knee joint injury were at two to three times the risk of a recurrent injury specific to that structure the following season. Kucera et al. (2005) reported an increased risk of ankle and knee injuries in youth soccer players who had sustained one previous injury to the same site (ankle injury rate ratio [IRR], 4.19; 95% CI, 2.97–5.92), knee IRR, 5.84; 95% CI, 4.04–8.44) and an even greater risk in players who reported multiple ankle injuries (ankle IRR, 8.16; 95% CI, 4.89–13.61). Arnason et al. (1996) report the proportion of all muscle strain injuries and ligament sprain injuries to be 44% and 58%, respectively. For ankle sprain injuries specifically, studies have reported 61% to 69% as recurrent sprains (Arnason et al. 1996; Kofotolis et al. 2007). Faude et al. (2005) report a fivefold increased risk of ACL injury in players with a previous ACL injury (IRR, 5.24; 95% CI, 1.42–19.59)].

Sex

Sex has been previously discussed. In summary, the rates of injury in regular season game play reported are slightly lower in elite women's competition as compared with men's competition (Table 17.1). In practice (training) the rates of injury reported are similar for men and women. In tournament play, injury rates reported are higher than regular season play for both men and women. In addition, the rates of injury in tournament play are more similar for men and women.

By specific injury type, there is some indication that the greatest proportion of all injuries is ligament sprain (33–66%) in most studies in women's soccer (Engstrom et al. 1991; Faude et al. 2005; Junge et al. 2007). In other women's studies, muscle strains accounted for the greatest proportion of all injuries in women's soccer (Ostenberg & Roos 2000; Giza et al. 2005; Jacobson & Tegner 2007). In men's elite soccer, muscle strains accounted for the greatest proportion of injuries in the majority of studies (Albert 1983; Arnason 1996; Drawer & Fuller 2002; Hawkins et al. 2001; Walden et al. 2005; Hagglund et al. 2006; Dvorak et al. 2007). When examining the risk of ACL injury alone, the risk of injury in women's soccer was twofold to eightfold higher than that for men's (Arendt & Dick 1995; Bjordal & Arnoy 1997; Mihata et al. 2006).

Age

By age, higher rates of injury are typically found in the older age groups (Arnason 2004a; Kucera et al. 2005; Ostenberg & Roos 2000). Other studies examining female soccer players found no difference in injury rate by age group; however, the age range in these studies examining young female adult soccer players was tighter than in other studies (Faude et al. 2005; Soderman et al. 2001).

Anthropometrics

Arguably, weight is a modifiable risk factor, but it will be considered in combination with anthropometrics including height. Faude et al. (2005) demonstrated a ninefold increased risk of injury in female soccer players who are taller than 1 standard deviation above the mean height (IRR, 9.64; 95% CI, 1.96–58.52). Weight was not a risk factor in this study. Other studies have not found height, weight, or body-mass index to be risk factors for injury in soccer (Arnason et al. 2004a; Hagglund et al. 2006; Kucera et al. 2005; Ostenberg & Roos 2000; Witvrouw et al. 2003). Dvorak et al. (2000) found elite male players with <7.7% body fat to be at a greater risk of injury ($\chi^2 = 9.31$; $P = 0.002$).

Table 17.4 Severity of injury by time-loss categories (% of all injuries).

Study	Study Design (country, yr)	Population (sex, age, level of play, other)	Sample Size or Denominator Data
Adult Male			
Agel et al. (2007)	Descriptive (USA, 1988–2003)	Male college (NCAA) 15 yr	>22,000 G and >62,000 P
Arnason (1996)	Cohort (Iceland, 1991)	Men's elite (ages 18–34) 1 season	84 players
Drawer & Fuller (2002)	Cohort (Britain, 1994–1997)	Male Professional 2.5 yr	87,529 player-hr
Engstrom et al. (1990)	Cohort (Sweden)	Male (elite) 1 season	64
Hawkins et al. (2001)	Cohort (Britain, 1997–1999)	Male (91 professional football clubs) 2 yr	n = 2,376
Hagglund et al. (2006)	Cohort (Sweden, 2001–2002)	Male (ages 17–38, top elite divisions) 1 yr	n = 525
Luthje et al. (1996)	Cohort (Finland, 1993)	Adult (male, elite, ages 17–35) 1 season	n = 263
Peterson et al. (2000)	Cohort (Switzerland)	Adult + youth (age groups: adult, 16–18, 14–16; all levels: high through low) 1 yr	n = 264
Poulsen et al. (1991)	Cohort (Denmark 1986)	Adult (male, 21–30, varying levels) 1 year	n = 55
Walden et al. (2005)	Cohort (Europe, 2001–2002)	Professional (male, mean age 26) 1 season	n = 266
Adult Female			
Dick et al. (2007)	Descriptive (USA, 1988–2003)	Women's dollege (NCAA) 15 yr	20,447 G and 54,750 P
Engstrom et al. (1991)	Cohort (Sweden)	Female (21 yr, elite) 1 year	n = 41
Faude et al. (2005)	Cohort (Germany, 2003–2004)	Female (ages 17–27, elite, national league) 11 mo	n = 165
Jacobson & Tegner (2007)	Cohort (Sweden, 2000)	Female (ages 16–36, premiere league) 10 mo	n = 269
Ostenberg & Roos (2000)	Cohort (Sweden, 1996)	Female (ages 14–39) 7 mo	n = 123
Soderman et al. (2001b)	Cohort (Sweden, 1998)	Female (ages 20–25, elite) 7 mo	n = 146
Tournament			
Dvorak et al. (2007)	Cohort (Germany, 2006)	Male (FIFA World Cup, tournament)	2111 tournament player-hr
Junge et al. (2004c)	Cohort (International, 1998–2001)	Male + female tournament (12 international)	10,155 player-hr
Junge (2004b)	Cohort (International, 2002)	Male (international tournament)	2,111 player-hr
Junge et al. (2006)	Cohort (international, 2004)	Male and female Olympic Games	
Kibler (1993)	Cohort (USA, 1987–1990)	Male + female (ages 12–19, invitational tournament)	74,900 player-hr
Walden et al. (2007)	Cohort (Europe, 2004–2005)	MS Championship, WS Championship, MU Championship	MS = 368 WS =60 MU = 144

G = player-games; MS = Men's Senior; MU = Men's U-19; P = player-practices; WS = Women's Senior.

Injury Definition	Time Loss, 0 Days, Slight	Time Loss, 1–3 Days, Minimal	Time Loss, 4–7 Days, Mild	Time Loss, 8–28 Days, Moderate	Time Loss, >28 Days, Severe
Medical attention and time loss or restricted performance ⩾1 day + any dental injury			(⩽10 days) 83.3	(⩾10 days) 16.7	
Time loss					
Time loss		14.1	35.4	38	12.4
Time loss					
Time loss >2 days		(2–3 days) 10	23	45	23
Time loss		33.1	27.6	28.8	10.5
Medical attention			(<1 week) 50	35.6	14.4
All			52.2	32.4	15.4
Time loss		(<1 game) 28	(1 to <5 games) 54	(⩾5 games) 18	
Time loss		28	28	29	15
Medical attention and time-loss or restricted performance ⩾1 day + any dental injury (1994 onward)			(⩽10 days) 81	(⩾10 days) 19	
Time loss			(1–6 days) 49	(7–30 days) 36	(>30 days) 15
Time loss			(1–6 days) 51	(7–30 days) 36	(>30 days) 13
Time loss		17	22	39	22
Time loss			(1–6 days) 31	(7–30 days) 51	(>30 days) 18
Time loss			(1–6 days) 34	(7–30 days) 49	(>30 days) 18
Medical attention (team physician)	2002/2006 33/30	37/33	17/15	11/18	2/5
Medical attention + time loss	48–70	17–36	1–18	2–17	0–3
Medical attention	32.9	36.7	17.1	11.4	1.9
Medical attention	M/F 58/53	32/25	4/13	3/8	3/3
Medical attention or time loss			(0–7 days) 62.5	(>7 days) 28.8	(season) 8.6
Medical attention	MS/WS/U19 0/17/0	47/44/47	13/0/18	13/22/29	27/17/6

Female Hormones

In the examination of risk factors specifically for ACL injuries in female athletes, Shultz et al. (2005) reported an association between hormone fluctuations through the menstrual cycle and anterior knee joint laxity. The only epidemiologic evidence found in women's soccer specifically, demonstrated higher rates of acute injury during the premenstrual and menstrual phases as compared with the rest of the cycle (Moller-Nielsen & Hammar 1989). Myklebust et al. (1998) also found European handball players to be more susceptible to injury during the menstrual phase. On the other hand, Wojtys et al. (2002) found female athletes to be more susceptible to ACL injuries during the ovulation phase. As such, the relationship between the phase of the menstrual cycle in which a female athlete is more susceptible to ligament injury is inconclusive to date.

Modifiable Intrinsic Risk Factors

Fitness Level and Endurance

There is some evidence that poor endurance is a risk factor for sport injury in male and female army trainees (male IRR, 2.8; 95% CI, 1.2–6.7); female IRR, 1.69; 95% CI, 1.45–7.92)] (Jones et al. 1993). In soccer, study findings in men's and women's soccer have not found endurance based on estimated Maximal oxygen consumption, VO_{2max} to be associated with injury risk (Arnason et al. 2004c; Ostenberg & Roos 2000). This finding may be related to the homogeneity of overall higher fitness levels in soccer athletes.

Flexibility and Joint Laxity

Witvrouw et al. (2003) found decreased levels of preseason hamstring and quadriceps flexibility in male professional soccer players who subsequently sustained a hamstring or quadriceps strain injury. Arnason et al. (1996), however, were unable to demonstrate a significant association between muscle flexibility and muscle strain injury. Soderman et al. (2001) demonstrated greater side-to-side differences in ankle dorsiflexion (odds ratio [OR], 7.06; $P = 0.02$) and hamstring flexibility (OR, 3.56; $P = 0.049$) in female players who subsequently sustained an overuse injury only. Inklaar et al. (1994b) found a correlation between decreased adductor muscle flexibility and subsequent adductor muscle injury. A similar association between hamstring muscle flexibility and hamstring muscle injury was not found. As such, based on few studies, there are insufficient data to conclude that there is a clear relationship between flexibility and injury in soccer.

General joint laxity and knee hyperextension were both found to be predictive of traumatic injury in female soccer players (laxity: OR, 3.1; $P = 0.03$; hyperextension: OR, 2.5; $P = 0.03$) (Soderman et al. 2001). Consistent with these findings, Ostenberg & Roos (2000) also found generalized joint laxity to be predictive of injury in female players (OR, 4.3; $P < 0.001$). Arnason et al. (1996) found medial knee instability to be associated with knee injuries in male soccer players; however, there was no association found between ankle instability and ankle injury in the same study. With few studies examining joint laxity or instability as a risk factor for injury in soccer, firm conclusions cannot be drawn.

Strength

Female soccer players with a lower hamstring: quadriceps strength ratio (i.e., based on concentric-muscle-strength testing using an isokinetic dynamometer) have been shown to be at a greater risk of injury (Soderman et al. 2001, Knapik et al. 1991). Orchard et al. (1997) also demonstrated an increased risk of hamstring injury in players with lower hamstring strength and decreased hamstring:quadriceps ratio. In contrast, Ostenberg and Roos (2000) were unable to demonstrate an association between isokinetic concentric muscle strength and injury in female soccer players. Ostenberg and Roos (2000) examined vertical jump as a functional lower-extremity strength measure and found no association with injury in adult female soccer players. Despite these nonsignificant findings examining all injury risk, there is certainly a trend toward increased risk associated with low hamstring: quadriceps ratio for lower extremity and hamstring strain injury in soccer.

Neuromuscular Control and Balance

Soderman et al. (2001) found low postural sway to be predictive of injury in female soccer players. Osterberg and Roos (2000) found higher performance on the square-hop test to also be predictive of injury in female soccer players. In addition, neuromuscular training programs including a balance-training component have been consistently effective in decreasing the risk of injury in soccer players (Caraffa et al. 1996, Emery & Meeuwisse 2008, Hewett et al. 1999, Mandelbaum et al. 2005, McGuine & Keene 2006).

There are very few studies including soccer players that examine biomechanical risk factors for injury using a prospective design. Soderman et al. (2001) did not find static measures of alignment including quadriceps angle, knee or foot alignment to be predictive of injury. Hewett et al. (2005) prescreened 205 female athletes (including soccer players) and were able to determine that athletes who subsequently sustained an ACL injury had a 2.5-fold greater knee abduction moment, 20% greater ground reaction force, and 16% shorter stance time than noninjured athletes on a drop vertical jump test. In fact, knee abduction moment had a sensitivity of 78% and a specificity of 73% in predicting ACL injury. A linear regression model including the most highly significant predictors (knee abduction angles, knee abduction moments, and side-to-side differences in these measures) of ACL injury showed a predictive r^2 value of 0.88. These findings are monumental in the understanding of dynamic neuromuscular factors associated with injury that will lead to further refinement of neuromuscular training prevention strategies in soccer.

Psychological and Social Factors

Dvorak et al. (2000) confirmed previous findings in other sports that life-event stress and poor reaction time were associated with injury in male soccer players. Is has been hypothesized that life-event stress reduces attention and mental performance, which in turn reduces reaction time in an athletic situation, leading to injury (Junge 2000). Taimela et al (1990) also found poor reaction time to be predictive of injury in soccer. Steffen (2008) demonstrated a significantly increased risk of injury in female youth soccer players with a high level of perceived life stress as compared with those with a perceived low level of life stress (OR, 1.67; 95% CI, 1.3–2.18). In addition, players with a high perceived "mastery climate" were also at an increased risk of injury ($P = 0.026$). Schwebel et al. (2007) findings suggest that inhibition, risk taking and aggression are not predictive of injury in youth male soccer players. It should be noted, however, that the small sample size (n = 60), few injuries (n = 6), and multiple comparisons lead to a likelihood of low study power associated with a type II statistical error.

Nonmodifiable Extrinsic Risk Factors

Level of Play and Experience

In most studies examining level of play, there is consistently a greater risk of injury reported in higher levels of play. By division of play in elite adult soccer, Agel et al. (2007) report the greatest rates of game injury across 15 years of men's collegiate soccer in Division I as compared with Division III (RR, 1.4; 95% CI, 1.3–1.5) and in Division II as compared with Division III (RR, 1.3; 95% CI, 1.2–1.4). These differences were consistent for practices. Dick et al. (2007) reported similar findings across 15 years of women's collegiate soccer, with the greatest rates of game injury in Division I as compared with Division III (RR, 1.2; $P < 0.01$). There were no significant differences found in practices by division of play. Contrary to these findings, Poulsen et al. (1991) found a 1.8-fold increased risk of injury in lower-skilled players. Kucera et al. (2005) found a 38% to 48% reduced risk of injury with a greater number of years of soccer experience, as compared with players with ≤2 years of soccer experience.

Position of Play

Tscholl et al. (2007a) examined injury rates by player position during six women's top level tournaments and find no difference in overall injury rates or time-loss injury rates between forwards, midfielder, defenders and goalkeepers. LeGall et al. (2006), however, report greater rates of injuries sustained per player in defenders (2.2), followed by goalkeepers (2.0), midfielders (1.6), and forwards (1.5) in elite youth players over 10 seasons. Kucera et al. (2005) found the greatest risk of injury in defenders as compared with midfielders (IRR, 1.23; 95% CI, 1.00–1.51). Consistent with these findings, Faude et al. (2005) also found the greatest risk of injury in defenders, with strikers a close second as compared with goalkeepers and midfielders.

Modifiable Extrinsic Risk Factors

Playing Surface

Some studies have examined the risk of injury on natural grass as compared with artificial turf. Ekstrand et al. (2006) found no difference in injury risk on artificial turf as compared with natural grass in professional men's soccer. Arnason et al. (1996), however, demonstrated a greater than two-fold increased risk of injury on artificial turf as compared with natural grass. Steffen et al. (2007) finds no difference in the incidence of overall injury or acute onset injury on artificial turf and grass in female youth players over a season of play. However, the incidence of serious injury (>21 days of time lost) was greater on artificial turf (relative risk, 2.0; 95% CI, 1.3–3.1)]. Further examination of shoe type and shoe-surface interface is critical.

Rules

Penalties including a free kick or yellow or red card are intended to modify unsafe acts such as foul tackles (including tackles from behind) that potentially increase the risk of unnecessary injury in soccer. Junge et al. (2007) reported 29% of injuries to be caused by foul play, but only 50% of these resulted in a penalty sanctioned by the referee. Walden et al. (2007) reported foul play injuries in male, female, and U-19 European Championships to account for 37%, 17%, and 29% of all injuries, respectively. In regular season play, 23% of match injuries in men's elite soccer were a result of foul play. Fuller et al. (2004) report that foul challenges accounted for 30% of head and neck injuries analyzed in international soccer matches. Bjordal & Arnoy (1997)reported 58% of all women's ACL injuries and 42% of all male ACL injuries in soccer to be the result of tackling. For men, 64% were tackles from the side and for women 44% and 32%, respectively, were related to tackles from the side and front. Andersen et al. (2004a) examined how violations of the rules of the game contributed to injury through video analysis of 174 matches in professional men's football. They reported that less than one third of the injuries identified on video and 40% of the incidents with a high risk of injury resulted in a free kick being awarded. Only one tenth of these situations led to a yellow or red card. In addition, the agreement between the match referee and the expert referee panel reviewing the video was 85%. Clearly, foul play accounts for a significant portion of injury in all studies reporting these findings. Given the support for accuracy of penalties assigned, clearly a review of fair play is required to protect players from injury.

Equipment

Shin guards were introduced as mandatory equipment in 1991 in U.S. collegiate soccer to reduce the risk of lower-leg injuries (Agel et al. 2007). In a biomechanical study, Boden (1998) demonstrated a 41% to 77% reduction in load force with shin guards, depending on the type. Evidence is lacking, however, to support the effectiveness of shin guards in soccer. Agel et al. (2007) demonstrate no difference in the rates of lower leg and ankle fractures and contusions in the two seasons prior to this mandate and the 13 years following this change.

What Are the Inciting Events?

Player-to-player contact injuries accounted for 32% to 61% of all injuries in studies relying on self-reporting mechanism of injury (Nielsen & Yde 1989; Arnason et al. 1996; Luthje 1996; Hawkins et al. 2001; Emery et al. 2005, Faude et al. 2005; Agel et al. 2007; Dick et al. 2007). Agel et al. (2007) reported 16% of all injuries to be related to a slide tackle in men's collegiate soccer. Hawkins et al. (2001) report 32% of all match injuries to be related to tackling. Junge et al. (2007) reported 29% of injuries to be caused by foul play, but only 50% of these resulted in a penalty sanctioned by the referee. Walden et al. (2007) reported foul play injuries in male, female, and U-19 European Championships to account for 37%, 17%, and 29% of all injuries, respectively. In regular season play, 23% of all match injuries in men's elite soccer were a result of foul play.

Some studies have examined mechanism of injury through video analysis (Giza et al. 2003; Andersen et al. 2004a, 2004b, 2004c, Arnason et al. 2004a, Fuller et al. 2004; Tscholl et al. 2007a, 2007b). Andersen et al. (2004b) examined ankle sprain injuries and identified the primary mechanisms of injury to be tackling (53.8%), clearing, or shooting, during which there was forced plantar flexion associated with contacting the opponent's foot (15.4%), running (15.4%), landing after heading (7.7%), and other (7.7%). Giza et al. (2003) further examined the mechanism of ankle injury in four world soccer competitions and reported weight bearing of the injured limb 54% of the time.

Andersen et al. (2004c) further examined through video analysis the mechanism of 192 head contact incidents that involved stoppage in play because of a suspected injury. Sixteen of these resulted in head injuries causing time loss. The most common playing action for these was heading duel (58%). The body part that hit the player was the elbow, arm, or hand (41%), followed by the head (32%), and foot (13%). In cases in which there was contact of the elbow, arm, or hand, the elbow was above shoulder level 85% of the time, active 77% of the time, and intentional 20% of the time. The authors suggest a potential rule change related to elbow use. Fuller et al. (2004) further report through video analysis that foul challenges account for 30% of head and neck injuries analyzed in international soccer matches.

Arnason et al. (2004a) examined 95 incidents from 52 matches captured on video and identified based on referee stoppage in play because of a suspected injury. Duels caused 88% of the incidents, of which 64% were tackling duels. The player sustaining the incident was reportedly focused away from the opponent 93% of the time. The primary mechanisms observed were breakdown attacks, tackling from the front or side with attention focused on the ball (24%), defensive tackling duels with attention focused on the ball or low ball control (20%), and heading duels with attention focused on the ball in the air (13%). The authors concluded that player attention and ball control may be important factors in the prevention of injuries.

In examining mechanism of injury in women's soccer, Tscholl et al. (2007b) identified 86% to be a result of direct contact with another player. Of these, 52% resulted from tackles from the side, 38% tackles from the front, and 11% tackles from behind. One-footed (65%) and upper body (21%) tackling actions were the most common. This study highlighted some differences in mechanisms of injury as compared with similar studies examining elite men's soccer. Tackles from behind were rarely seen in women's soccer, and slide-in tackles resulting in injury were much more common. In addition, the use of elbows in aerial challenges was rarely a cause of injury in women's soccer.

Injury Prevention

To date, there have been 17 prospective studies examining the effectiveness of injury-prevention programs specifically in soccer (Table 17.5). The majority of the prevention strategies (12 of 15) examined include a neuromuscular training program aimed at reducing injuries. These programs consistently include various specific components of balance, agility, endurance, and strength training (Ekstrand et al. 1983; Tropp et al. 1985; Caraffa et al. 1996; Hewett et al. 1999; Heidt et al. 2000; Soderman et al. 2000; Junge et al. 2002; Askling et al. 2003; Mandelbaum et al. 2005; McGuine & Keene 2006; Hagglund et al. 2007; Emery & Meeuwisse 2008; Engebretsen et al. 2008; Steffen 2008;) (Table 17.5). Other intervention studies have examined an educational video-based awareness program (Arnason et al. 2005), ankle braces (Tropp et al. 1985; Surve et al. 1994) and cognitive behavioral training (Johnson et al. 2005). All studies demonstrated a protective effect of the intervention with a reduction of injury in the intervention group ranging from 38% to 88% reduction (Ekstrand et al. 1983; Tropp et al. 1985; Surve et al. 1994; Caraffa et al. 1996; Heidt et al. 2000; Askling et al. 2003; Johnson et al. 2005; Mandelbaum et al. 2005; McGuine &

Table 17.5 Injury-prevention studies.

Study	Study Design (country follow-up period)	Population (sex, age, level of play, other)	Type of Study (no. of players/no. of teams)
Neuromuscular training interventions			
Askling et al. (2003)	RCT Sweden 11 mo	Elite male Mean age 24 Premier league Division 1	Intervention (15/2) Control (15/2)
Caraffa et al. (1996)	Quasi-experimental Italy 3 yr	Semi-professional + amateur Age unknown	Total (600) Intervention (20) Control (20)
Ekstrand et al. (1983)	RCT 6 mo	Amateur male Ages 17–37	Total (180/12) Intervention (6) Control (6)
Emery & Meeuwisse (2008)	RCT[a] Canada 6 mo	Youth club soccer Ages 13–18 Premier	Intervention (380/32) Control (364/28)
Engebretsen et al. (2008)	RCT Norway 8 mo	Elite male Previous injury or reduced function in the ankle, knee, hamstring, or groin	Total (508/31) HR control (195) HR intervention (193) LR control (120)
Hagglund et al. (2007)	RCT Sweden 10 mo	Amateur male Age 15–46 yr 4th Division	Intervention (241/10) Control (241/10)
Heidt et al. (2000)	Quasi-experimental USA 1 year	Female youth High school Ages 14–18	Intervention (42) Control (258)
Hewett et al. (1999)	Quasi-experimental USA 1 yr	Youth (male + female) Age 14–18 yr Soccer, basketball, and volleyball	Intervention (366/15) [girls] Control 1 (463/15) [girls] Control 2 (434/13) [boys]

Targeted Injuries	Intervention	Injury Rates (no. of injuries/1,000 player-hr, unless otherwise stated)	Effect of Intervention
Hamstring strains	Preseason concentric and eccentric hamstring strengthening program (16 sessions-10 wk)	Intervention: 3 injuries Control: 10 injuries	IRR (estimate), 0.3 70% reduction in injury
ACL injury	Preseason and in season proprioceptive training program (balance) (30 days preseason, 3x/wk in season)	Intervention (10 injuries): 0.15 injuries/team/season Control (60 injuries): 1.15 injuries/team/season	IRR (estimate), 0.13 87% reduction in injury
All injury	Multifaceted program	(training, equipment, ankle taping, rehabilitation, exclude if severe knee instability, education, disciplined play, correction and supervision by doctor(s) and physiotherapist(s).	IRR (estimate), 0.25 70% reduction in injury
All injuries, acute-onset injury, ankle and knee sprains	Neuromuscular training program (balance, agility, jump technique, eccentric quads/ hamstrings, core stability)	Intervention: All, 3.35 (95% CI, 2.65–4.17) Acute, 3.05 (95% CI, 2.39–3.84) All, 2.08 (95% CI, 1.54–2.74 Acute,1.75 (95% CI, 1.26–2.34)	IRR (all), 0.67 (95% CI, 0.43–1.04) n.s. IRR (acute onset), 0.62 (95% CI, 0.39–0.96) IRR (ankle sprain), 0.57 (95% CI, 0.28–1.16) [NS]. Control: IRR (knee sprain), 0.38 (95% CI, 0.08–1.86) [NS] 38% reduction in acute-onset injury
Ankle and knee sprains, hamstring and groin strains	Targeted neuromuscular (balance) and/or strength training (eccentric, core) program dependent on previous injury and/or function	HR intervention, 4.9 (95% CI, 4.3–5.6) HR control, 5.3 (95% CI, 4.6– 6.0) LR control, 3.2 (95% CI, 2.5–3.9)	HR intervention vs. HR control: IRR, 0.94 (95% CI, 0.77–1.13) [NS] No effect LR control vs. HR intervention: IRR, 0.65 (95% CI, 0.51–0.85) LR control vs. HR control: IRR, 0.61 (95% CI, 0.48–0.79)
All injury	Education regarding risk factors for reinjury, rehabilitation principles, and a 10-step progressive rehabilitation program including return-to-play criteria.	Intervention: Practice 3.3 (95% CI,2.6–4.2 Game 10.5 (95% CI, 8.3–13.2) Reinjury 2.3 (95% CI, 1.4–3.9) Control: Practice 2.7(95% CI, 2.1–3.5) Game 12.3 (95% CI, 9.9–15.3) Reinjury 8 (95% CI, 5.9–11)	Practice: IRR (estimate) = 1.22 ($P > 0.05$) n.s. Game IRR (estimate) = 0.85 ($P > 0.05$) n.s. Reinjury: Hazard ratio (all reinjury), 0.34 (95% CI, 0.16–0.72) Hazard ratio (LE reinjury), 0.25 (95% CI, 0.11–0.57) 66% reduction in all reinjury 74% reduction in LE reinjury
All injury	Preseason conditioning (CV, plyometrics, agility, strength, flexibility) 7-weeks; 1–2x/wk	Intervention: 16.7 injuries/100 players Control: 35.3 injuries/100 players	IRR (estimate) = 0.47 53% reduction in all injury
Serious injury ACL/MCL	Neuromuscular training program (flexibility, jump training, agility) 60–90 minutes 3x/week, 6 mo	Intervention (girls): 0.22 injuries/1,000 exposures Control (girls): 0.52 injuries/1,000 exposures Control (boys): 0.09 injury/1,000 exposures	Intervention vs. Control (girls) IRR (estimate) = 0.42 ($P = 0.11$) n.s. Intervention vs. Control (boys) IRR (estimate) = 2.47 ($P = 0.46$) n.s. Control (girls) vs. Control (boys) IRR (estimate) = 5.78 ($P = 0.08$) n.s. No effect. Trend toward reduction in intervention group

(*continued*)

Table 17.5 (*continued*)

Study	Study Design (country follow-up period)	Population (sex, age, level of play, other)	Type of Study (no. of players/no. of teams)
Junge et al. (2002)	Quasi-experimental Switzerland 2 seasons	Male youth Age 14–19 yr	Total 194
Mandelbaum et al. (2005)	Cohort USA 2 yr	Female youth 12–18 yr	Year 1: Intervention (1,041/52) Control (1,905/95) Year 2: Intervention (844/45) Control (1,913/112)
McGuine & Keene (2006)	RCT USA 1 season	Male + female High school soccer and basketball Mean age 16	Intervention (473/27) Control (458/28)
Soderman et al. (2000)	RCT Sweden 7 mo	Female amateur Mean age 20	Intervention (121/7) Control (100/6)
Steffen (2008)	RCT[a] Norway 8 mo	Female youth Ages 14–16	Intervention (1,073/58) Control (947/51)
Other Intervention Studies			
Arnason et al. (2005)	RCT Iceland (6 mo)	Elite male Age unknown Divisions 1 and 2	Intervention (127/7) Control (144/8)
Johnson et al. (2005)	RCT Sweden 6 mo	Elite male + female high injury risk Mean age: Men, 22.9 Women, 20.1	Intervention (16) Control (16)
Surve et al. (1994)	RCT South Africa 1 season	Senior male	Previous ankle sprain (258) No previous sprain (246)
Tropp et al. (1985)	RCT Sweden 6 mo	Amateur male	Total (439/25)

ACL = anterior cruciate ligament; CI = confidence interval; F-MARC = FIFA Medical Assessment and Research Centre; HR = high-risk; ratio; RCT = randomized controlled trial.
[a]effect estimates adjusted for effect of clustering.

Targeted Injuries	Intervention	Injury Rates (no. of injuries/1,000 player-hr, unless otherwise stated)	Effect of Intervention
All injury	Multifaceted program (warm-up, cool down, taping unstable ankles, rehabilitation, fair play, F-MARC bricks-flexibility, strength, agility, coordination, endurance)	Intervention: 6.71 Control: 8.48	IRR (estimate), 0.79 [NS] No effect. Trend toward reduction in intervention group
ACL injury	Neuromuscular training program (warmup including flexibility, strength, plyometrics, agility)	Intervention: 0.09 injuries/1,000 AEs Control: 0.49 injuries/1,000 AEs	IRR, 0.181 ($P < 0.0001$) 82% reduction in ACL injury
Ankle sprains	Balance training program (wobble board) 5x/wk for 4 wk, preseason 3x/wk in-season	Intervention: 1.13 Control: 1.87	IRR, 0.56 (95% CI, 0.33–0.95) 44% reduction in ankle sprains
Acute-onset lower-extremity injury	Home-based wobble board balance training program (daily for 30 days, 3x/wk for rest of season)	Intervention 4.75 Control 3.83	IRR, 1.24 (95% CI, 0.74–2.06) No effect
All injury	F-MARC 11 warm-up (core stability, balance, plyometrics, strength)	Intervention 3.6 (95% CI, 3.2–4.1) Control 3.7 (95% CI, 3.2–4.1)	IRR = 0.99 (95% CI, 0.83–1.19) No effect
Acute-onset injury	Educational video-based (15 min) awareness program (i.e. injuries, risk factors, mechanisms of injury)	Intervention 6.6 ± 0.7 Control 6.6 ± 0.7	IRR, 1.0 No effect
All injury	Cognitive behavioural training (relaxation, stress management, goal setting, self confidence training, critical incident diary) 6–8 inseason sessions	Intervention 0.22 injuries/player Control 1.31 injuries/player	IRR (estimate) = 0.17 ($p < 0.005$) 83% reduction in injury
Ankle sprain injury	Semirigid ankle brace (Sport-Stirrup)	Previous: Intervention: 0.14 Control: 0.86 No previous: Control: 0.46	Previous Sprain IRR = 0.16 84% reduction in ankle sprains in intervention group (previously injured) No effect in players without previous sprain
Ankle sprain injury	Ankle brace or balance training		71–82% reduction in players with previous sprains No effect in players without previous sprains

IRR = Incidence Rate Ratio; LE = Lower Extremity; LR = low-risk; MCL = medial collateral ligament; NS = not significant; OR = odds

Keene 2006; Hagglund et al. 2007; Emery & Meeuwisse 2008; Engebretsen et al. 2008). The exception are five studies that demonstrated no effect of intervention (Hewett et al. 1999; Soderman et al. 2000; Junge 2002; Arnason et al. 2005; Steffen 2008) (Table 17.5). It should be noted that compliance with intervention, particularly in the case of a home-program component, may be the key factor in studies showing no effect or a smaller effect size (Soderman et al. 2000; Steffen 2008). In the case of Hewett et al. (1999), the outcome measure was all serious knee injury. There were only 14 injuries, limiting the power to detect a significant difference but a significant trend was observed.

Four of the intervention studies have focused on female youth soccer players (Hewett et al. 1999; Heidt et al. 2000; Mandelbaum et al. 2005; Steffen 2008) and one on adult female soccer players (Soderman et al. 2000). Emery et al. (2008)and Johnson et al. (2005) and McGuine & Keene (2006)targeted male and female youth soccer players. The remaining nine studies targeted prevention in male soccer players, one of which targeted youth (Ekstrand et al. 1983; Tropp et al. 1985; Surve et al. 1994; Caraffa et al. 1996; Junge et al. 2002; Askling et al. 2003; Arnason et al. 2005; Hagglund 2007; Engebretsen et al. 2008).

Some studies reviewed targeted prevention of all injuries (Ekstrand et al. 1983; Heidt et al. 2000; Soderman et al. 2000; Junge et al. 2002; Arnason et al. 2005; Hagglund 2007; Emery 2008; Engebretsen et al. 2008; Steffen 2008). Other studies were targeting specific injury types, including ACL injury (Hewett et al. 1999), hamstring strains (Askling et al. 2003), and ankle sprains (Tropp et al. 1985; Surve et al. 1994). The study design used to examine the effectiveness of interventions in 11 of 16 studies was an RCT (Ekstrand et al. 1983; Tropp et al. 1985; Surve et al. 1994; Soderman et al. 2000; Askling et al. 2003; Arnason et al. 2005; Johnson et al. 2005; Hagglund 2007; Emery 2008; Engebretsen et al. 2008; Steffen 2008).

Despite the design of most studies, in which individual players were targeted for prevention in the context of a team intervention, only two studies adjusted for the effect of team (cluster) appropriately in the analysis (Emery 2008; Steffen 2008). The precision of estimates of effect in the other studies should thus be interpreted with caution (Emery 2007). Limitations of some of the studies examined, particularly nonrandomized designs, include potential selection bias and bias-associated confounding variables (Caraffa et al. 1996; Hewett et al. 1999; Heidt et al. 2000; Junge et al. 2002; Mandelbaum et al. 2005). Measurement bias is also certainly of concern in many of the studies reviewed in which injury surveillance had not been previously validated (Xxxxx et al. 1985; Caraffa et al. 1996; Heidt et al. 2000). In some studies, the sample size was small and nonsignificant findings may be related to low power (Hewett et al. 1999; Junge et al. 2002). Compliance is not assessed in most of the studies examined and is reportedly poor in two RCTs that examined prevention strategies in youth soccer (Emery 2008; Steffen 2008).

Many of the intervention studies including multifaceted training programs were effective in reducing injury in soccer. It remains unclear in many studies precisely which components are critical to prevention (Ekstrand et al. 1983; Hewett et al. 1999; Heidt et al. 2000; Junge et al. 2002; Mandelbaum et al. 2005; Hagglund et al. 2007; Emery et al. 2008). Some of these comprehensive and effective programs were also very time- and supervision-intensive. For example, Hewett et al. (1999) developed a 60- to 90-minute supervised program that was implemented for 6 months. Programs such as these may not be sustainable in some levels of soccer.

Regardless of program components, it is important to engage all stakeholders, including players, parents, trainers, coaches, and organizations in order to maximize uptake of prevention strategy and optimize benefit. Finch (2006) supports this notion in proposing a sports-injury research framework-the Translating Research into Injury Prevention Practice (TRIPP)-which builds on the fact that only research that can, and will, be adopted by sports participants, their coaches, and sporting bodies will prevent injuries. As such, it is critical that performance benefits of the program are also considered. Comprehensive training programs, including components of balance, strength, plyometrics, and agility training may improve performance in addition to biomechanical measures that have been demonstrated to be risk factors for injury in soccer (Myer et al. 2005, 2006; Pollard et al. 2006).

Further Research

Worldwide participation rates in soccer are high. High rates of injury in this population have a substantial impact on the player, the parents in the case of youth participants, and the health care system. Sports injury in soccer may also potentially affect future ability to participate and may have long-term health costs related to decreased levels of physical activity and osteoarthritis related to some injuries. Given these facts, it is critical to further evaluate the economic impact of injury in the most popular sport participated in worldwide. This would facilitate the greater participation of policy makers in the prevention of injuries in soccer.

Consistently, the majority of injuries in all studies examining injury across all age groups, levels of play, and both sexes are acute-onset lower-extremity injuries. Injury-prevention strategies should clearly target ankle and knee sprains and thigh and groin strains. Concussions and ACL injuries are also of particular concern because of potential long-term health outcomes.

The consistency of the evidence based on prospective study designs for nonmodifiable risk factors, including previous injury and sex for specific injury types such as ACL injuries for women is strong. These findings support targeting players with a history of injury for injury prevention. The strength of the evidence for potentially modifiable risk factors is weaker, based on fewer studies examining these factors prospectively. In addition, there are few studies that use a multifactorial approach to examining risk factors for injury in soccer, and hence lack of control for other potentially confounding variables threatens the internal validity of many of these studies. Future research examining potentially modifiable risk factors for injury in soccer must take a multifactorial approach and further should consider the dynamic and recursive nature of injury risk as proposed by Meeuwisse et al. (2007).

Research examining precise injury mechanisms through video analysis has added substantially to the understanding of injury risk in soccer and will contribute to the ongoing research in injury prevention in soccer. For example, it is clear that elbowing in elite men's soccer requires further examination with regard to potential rule changes that may further penalize such intentional contact.

Although there is limited RCT evidence supporting preventive training programs in soccer to reduce the risk of injury, there are several studies that support the protective effects of a neuromuscular training program in reducing the risk of injury or reinjury (Ekstrand et al. 1983; Caraffa et al. 1996; Heidt et al. 2000; Askling et al. 2003; Mandelbaum et al. 2005; McGuine & Keene 2006; Hagglund 2007; Emery 2008; Engebretsen et al. 2008). The consistency of the findings between youth and adult studies is also encouraging. These programs all contain some element of balance, strength, agility, core stability (or some combination of these) training. It remains unclear what the optimal components and duration of neuromuscular training are essential to provide a protective effect soccer. The studies demonstrating no effect have smaller sample sizes, are targeting specific injury types with lower injury rates, report poor compliance, or do not report compliance with the program.

Although there has been little attention to date on the prevention of overuse injuries in soccer, this may reflect the lack of knowledge and consistency related to overuse-injury definitions and surveillance to capture these injuries. Further attention is required to develop consistent definitions, evaluate risk factors, and implement and evaluate prevention strategies targeting overuse injuries in soccer players.

Future studies examining prevention strategies in soccer must further examine strategies for program delivery in order to optimize compliance and have the greatest effect on reducing injury in soccer. The analysis strategy used to examine the effectiveness of interventions must consider cluster effects of teams in the analysis. It is also critical to continue to integrate basic science, laboratory, and epidemiologic research to maximize the understanding of mechanisms of injury, risk factors for injury, optimal prevention strategies, complete and appropriate treatment (i.e., medical, surgical, rehabilitation) and long-term effects of injury in soccer. Long term follow-up studies should be part of the future plan for research in injury prevention in soccer. These studies will be critical in quantifying the long-term impact of soccer injuries on future sports participation and the implications for the future health of our population (i.e., the development of osteoarthritis and other disease morbidity and mortality). What we learn from research in elite levels of soccer will certainly impact future research in more recreational populations.

References

Agel, J., Evans, T., Dick, R., Putukian, M. & Marshall, S. (2007). Descriptive epidemiology of collegiate men's soccer injuries: National Collegiate Athletic Association Injury Surveillance System, 1988–1989 through 2002–2003. *Journal of Athletic Training* **42,** 270–277.

Albert, M. (1983) Descriptive three year study of outdoor and indoor professional soccer injuries. *Athletic Training* **Fall,** 218–220.

Andersen, T.E., Engebretsen, L. & Bahr, R. Rule violations as a cause of injuries in male Norwegian professional football: are referees doing their job? (2004a) *American Journal of Sport Medicine* **32**(suppl. 1):62S–68S.

Andersen, T.E., Floerenes, T.W., Arnason, A. & Bahr, R. Video analysis of the mechanisms for ankle injuries in football. (2004b) *American Journal of Sport Medicine* **32**(suppl. 1):69S–79S.

Andersen, T.E., Arnason, A., Engebretsen, L. & Bahr, R. Mechanisms of head injuries in elite football. (2004c) *British Journal of Sport Medicine* **38,** 690–696.

Angus, D.E., Cloutier, E. & Albert, T. (1998) *The economic burden of unintentional injury in Canada*. SmartRisk and Health Canada, Kingston, ON.

Arendt, E. & Dick, R. (1995) Knee injury patterns among men and women in collegiate basketball and soccer. NCAA data and review of the literature. *American Journal of Sport Medicine* **23**, 694–701.

Arnason, A., Engebretsen, L. & Bahr, R. (2004a) A prospective video-based analysis of injury situations in elite male football: football incident analysis. *American Journal of Sport Medicine* **32,** 1459–1465.

Arnason, A., Engebretsen, L. & Bahr R. (2005) No effect of a video-based awareness program on the rate of soccer injuries. *American Journal of Sports Medicine* **33,** 77–84.

Arnason, A., Gudmundsson, A., Dahl, H.A. & Johannsson, E. (1996). Soccer injuries in Iceland. *Scandinavian Journal of Medicine & Science in Sports* **1**, 40–45.

Arnason, A., Sigurdsson, S.B., Gudmundsson, A., Holme, I. & Bahr, R. (2004b) Risk factors for injuries in football. *American Journal of Sport Medicine* **32,** S5–S16.

Arnason, A., Sigurdsson, S.B., Gudmundsson, A., Holme, I., Engebretsen L. & Bahr, R. (2004c) Physical fitness, injuries and team performance in soccer. *Medicine & Science in Sports & Exercise* **36**, 278–285.

Askling, C., Karlsson, J. & Thorstensson, A. (2003) Hamstring injury occurrence in elite soccer players after preseason strength training with eccentric overload. *Scandinavian Journal of Medicine & Science in Sports* **13,** 244–250.

Beltrami, G., Terrell, R., Holzgraefe, M., Charles, R. & Dvorak, J. (2006) Injuries in team sport tournaments during the 2004 Olympic Games. American Journal of Sports Medicine 32: 565-676.

Bjordal, J. & Arnoy, F. (1997) Epidemiology of anterior cruciate ligament injuries in soccer. *American Journal of Sport Medicine* **25,** 341–346.

Blair, S.N. (1993) Physical activity, physical fitness and health. *Research Quarterly in Exercise and Sport* **64,** 365–376.

Blair, S.N., Kohl, H.W. & Barlow, C.E. (1995) Changes in physical fitness and all-cause mortality: a prospective study of healthy and unhealthy men. *JAMA* **273,** 1093–1098.

Boden, B. (1998) Leg injuries and shin guards. *Clinical Journal of Sports Medicine* 17**,** 769–777.

Caraffa A., Cerulli G., Projetti M., Aisa G., Rizzo A. (1996) Prevention of anterior cruciate ligament injuries in soccer: a prospective controlled study of proprioceptive training. *Knee Surgery Sports Traumatology & Arthroscopy* **4,** 19–21.

Canadian Soccer Association (CSA). (2007) 2007 Demographics: Player registration. http://www.canadasoccer.com/documents/demographics/2007_demographics_report.pdf [accessed on May 12, 2008]

Delaney, J.S., Lacroix, V.J. & Leclerc, S. (2002) Concussion among university football and soccer players. *Clinical Journal of Sport Medicine* **12,** 331–338.

Dick, R., Putukian, M., Agel, J., Evans, T.A. & Marchall, S.W. (2007). Descriptive epidemiology of collegiate women's soccer injuries: National Collegiate Athletic Association Injury Surveillance System, 1988–1989 through 2002–2003. *Journal of Athletic Training* **42,** 278–285.

Drawer, F. & Fuller, C.W. (2001) Propensity for osteoarthritis and lower limb joint pain in retired professional soccer players. *British Journal of Sports Medicine* **35,** 402–408.

Drawer, S. & Fuller CW. (2002) Evaluating the level of injury in English professional football using a risk based assessment process. *British Journal of Sport Medicine* **36,** 446– 451.

Dvorak, J. & Junge, A. (2000) Football injuries and physical symptoms. *American Journal of Sport Medicine* **28**, S3–S9.

Dvorak, J., Junge, A., Grimm, K. & Kirkendall, D. (2007a) Medical report from the 2006 FIFA World Cup Germany. *British Journal of Sport Medicine* **41,** 578–581.

Ekstrand, J., Gillquist, J. & Liljedahl S.O. (1983) Prevention of soccer injuries: supervision by doctor and physiotherapist. *American Journal of Sports Medicine* **11,** 116–120.

Ekstrand, J., Timpka, T. & Hagglund, M. (2006) Risk of injury in elite football played on artificial turf vs. natural grass—a prospective two-cohort study.

British Journal of Sport Medicine **40,** 975–980.
Elias, S. (2001) 10-year trend in USA Cup soccer injuries: 1988–1997. *Medicine and Science in Sports and Exercise* **33,** 359–367.
Emery, C. (2003) Risk factors for injury in child and adolescent sport: a systematic review of the literature. *Clinical Journal of Sport Medicine***13,** 256–268.
Emery, C.A. (2007) Considering cluster analysis in sport medicine and injury prevention research. *Clinical Journal of Sports Medicine* **17,** 211–214.
Emery, C.A. & Meeuwisse, W.H. (2008) The effectiveness of an injury prevention program to reduce injuries in adolescent soccer (abstract). *British Journal of Sport Medicine* **42,** 497.
Emery, C.A., Rose, M.S., Meeuwisse, W.H. & McAllister, J.R. (2007) The effectiveness of an injury prevention strategy in high school basketball: a cluster-randomized controlled trial. *Clinical Journal of Sports Medicine* **17,** 17–24.
Emery, C.A., Meeuwisse, W.H. & Hartmann S.E. (2005) Evaluation of risk factors for injury in adolescent soccer. Implementation and validation of an injury surveillance system. *American Journal of Sports Medicine* **33**:1–10.
Emery CA, Meeuwisse WH. (2008) The effectiveness of a neuromuscular training program to reduce injuries in youth soccer. A cluster-randomized controlled trial. *Br J Sport Med* **42**:497.
Engebretsen, A.H., Myklebust, G., Holme, I., Engebretsen, L. & Bahr, R. (2008) Prevention of injuries among male soccer players: a prospective, randomized intervention study targeting players with previous injuries or reduced function. *American Journal of Sports Medicine* **36,** 1052–1060.
Englund, M., Roos, E.M., & Lohmander, L.S. (2003) Impact of type of meniscal tear on radiographic and symptomatic knee osteoarthritis: a sixteen year follow-up of meniscectomy with matched controls. *Arthritis and Rheumatism* **48,** 2178–2187.
Engstrom, B., Forssblad M. & Johansson, C. (1990) Does a major knee injury definitely sideline an elite soccer player? *American Journal of Sports Medicine* **18,** 101–105.
Engstrom, B., Johansson, C. & Tornkvist, H. (1991) Soccer injuries among elite female players. *American Journal of Sports Medicine* **19,** 372–375.
Faude, O., Junge, A., Kindermann, W. & Dvorak J. (2005) Injuries in female soccer players: a prospective study in the German national league. *American Journal of Sports Medicine* **33,** 1694–1700.
Finch, C. (2006) A new framework for research leading to sports injury prevention. *Journal of Science & Medicine in Sport* **9,** 3–9.
FIFA. (2007) FIFA big count 2006: 270 million people active in football. http://www.fifa.com/aboutfifa/media/newsid=529882.html [accessed on May 12, 2008]
FIFA. (2008a) About FIFA. http://www.fifa.com/aboutfifa/federation/index.html [accessed on May 12, 2008]
FIFA. (2008b) Classic football: history of the game. http://www.fifa.com/classicfootball/history [accessed on May 12, 2008]
Fuller, C.W., Ekstrand, J., Junge, A., Andersen, T.E., Bahr, R., Dvorak, J., Hagglund, M., McCrory, P. & Meeuwisse, W.H. (2006). Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries.*British Journal of Sports Medicine* **40,** 193–201; *Scandinavian Journal of Medicine and Science in Sports* **16,** 83–92; *Clinical Journal of Sport Medicine* **16,** 97–106.
Fuller C.W., Smith, G.L. & Junge A. (2004) The influence of tackle parameters on the propensity for injury in international football. *American Journal of Sports Medicine* **32**(suppl. 1), S43–S53.
Giza, E., Fuller C.W., Junge, A. & Dvorak, J. (2003) Mechanisms of foot and ankle injuries in soccer. *American Journal of Sports Medicine* **31,** 550–554.
Giza, E., Mithofer, K., Farrell, L., Zarins, B. & Gill, T. (2005) Injuries in women's professional soccer. *British Journal of Sports Medicine* **39,** 212–216.
Grimmer, K.A., Jones, D. & Williams, J. (2000) Prevalence of adolescent injury from recreational exercise: an Australian perspective. *Journal of Adolescent Health* **27,** 1–6.
Griffin, L.Y., Albohm, M.J., Arendt, E.A., Bahr, B.D., Demaio, M., Dick, R.W., Engebretsen, L., Garrett, W.E. Jr., Hannafin, J.A., Hewett, T.E., Huston, L.J., Ireland, M.L., Johnson, R.J., Lephart, S., Mandelbaum, B.R., Man, B.J., Marks, P.H., Marshall, S.W., Myklebust, G., Noyes, F.R., Powers, C., Shields, C. Jr., Shultz, S.J., Silvers, H., Slauterbeck, J., Taylor, D.C., Teitz, C.C., Wojtys, E.M. & Yu, B. (2006) Understanding and preventing noncontact anterior cruciate ligament injuries: a review of the Hunt Valley II meeting, January 2005. *American Journal of Sports Medicine* **34,** 1512–1532.
Hagglund M., Walden, M. & Ekstrand, J. (2006) Previous injury as a risk factor for injury in elite football: a prospective study over 2 consecutive seasons. *British Journal of Sports Medicine* **40,** 767–772.
Hagglund, M., Walden, M. & Ekstrand J. (2007) Lower reinjury rate with a coach-controlled rehabilitation program in amateur male soccer: a randomized controlled trial. *American Journal of Sports Medicine* **35,** 1433–1442.
Hawkins, R.D. & Fuller CW. (1999) A prospective epidemiological study of injuries in four English professional football clubs *British Journal of Sports Medicine* **33,** 196–203.
Hawkins, R.D., Hulse, M.A. & Wilkinson, C. (2001) The Football Association Medical Research Programme: an audit of injuries in professional football – analysis of preseason injuries. *British Journal of Sports Medicine* **35,** 43–47.
Heidt, R.S., Jr., Sweeterman, L.M., Carlonas, R.L., Traub, J.A. & Tekulve, F.X. (2000) Avoidance of soccer injuries with preseason conditioning. *American Journal of Sports Medicine* **28,** 659–662.
Hewett T.E., Myer, G.D. & Ford, K.R. (2006) Anterior cruciate ligament injuries in female athletes: part 1, mechanisms and risk factors. *American Journal of Sports Medicine* **34,** 299–311.
Hewett, T.E., Lindenfeld, T.N., Riccobene, J.V., & Noyes, F.R. (1999) The effect of neuromuscular training on the incidence of knee injury in female athletes. *American Journal of Sports Medicine* **27,** 699–705
Hewett T.E., Myer, G.D., Ford, K.R., Heidt, R.S. Jr., Colosimo, A.J., McLean, S.G., van den Bogert, AJ, Paterno, M.V. & Succop, P. (2005) Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes *American Journal of Sports Medicine* **33,** 492–501.
IOC. (2008) Football history. http://www.fifa.com/classicfootball/history/# [accessed on May 12, 2008]
Inklaar, H. (1994a) Soccer injuries I: Incidence and severity. *Sports Medicine* **18,** 55–73.
Inklaar, H. (1994b) Soccer injuries II: Aetiology and prevention. *Sports Medicine* **18,** 81–93.

Inklaar, H., Bol, E., Schmikli, S.L. & Mosterd, W.L. (1996) Injuries in male soccer players: team risk analysis. *International Journal of Sport Medicine* **17,** 229–234.

Jacobson, I. & Tegner, Y. (2007) Injuries among Swedish female elite football players: a prospective population study. *Scandinavian Journal of Medicine & Science in Sport* **17,** 84–91.

Jebb, S. & Moore, M. (1999) Contribution of a sedentary lifestyle and inactivity to the etiology of overweight and obesity: current evidence and research issues. *Medicine & Science in Sports and Exercise* **31,** S534–S541.

Johnson, U., Ekengren, J. & Andersen, M.B. (2005) Injury prevention in Sweden: helping soccer players at risk. *Journal of Sport and Exrcise Psychology* **27,** 32–38.

Jones, B.H., Bovee, M.W., Harris, J.M. (1993) Intrinsic risk factors for exercise related injuries among male and female army trainees. *American Journal of Sport Medicine* **21,** 705–710.

Junge, A. (2000) The influence of psychological factors on sports injury: review of the literature. *American Journal of Sports Medicine* **28**(suppl.), S16–S21.

Junge, A., Rosch, D., Peterson, L., Graf-Baumann, T. and Dvorak, J. (2002) Prevention of soccer injuries: a prospective intervention study in youth amateur players. American Journal of Sports Medicine 30, 652-659.

Junge, A., Cheung, K., Edwards, T. & Dvorak, J. (2004a) Injuries in youth amateur soccer and rugby players—comparison of incidence and characteristics. *British Journal of Sport Medicine* **38,** 168–172.

Junge, A., Dvorak, J. & Graf-Baumann, T. (2004b) Football injuries during the World Cup 2002. *American Journal of Sports Medicine* **32,** 23S–27S.

Junge, A., Dvorak, J., Graf-Baumann, T., & Peterson, L. (2004c) Football injuries during FIFA tournaments and the Olympic Games, 1998–2001: development and implementation of an injury-reporting system. *American Journal of Sports Medicine* 32(suppl.) 80S–89S.

Junge, A., Langvoort, G., Pipe, A., Peytavin, A., Wong, F., Mountjoy, M., Beltrami, G., Terrell, R., Holzgraefe, M., Charles, R. & Dvorak, J. (2006) Injuries in team sport tournaments during the 2004 Olympic Games. *American Journal of Sports Medicine* **32,** 565–676.

Junge, A. & Dvorak J. (2007) Injuries in female football players in top-level international tournaments. *British Journal of Sports Medicine* 41 Suppl 1: i3–7.

Kibler, W.B. (1993) Injuries in adolescent and preadolescent soccer players. *Medicine and Science in Sports and Exercise* **25**:1330–1332.

Knapik J.J., Bauman, C.L., Jones, B.H., Harris, J.M. & Vaughan, L. (1991) Preseason strength and flexibility imbalances associated with athletic injuries in female collegiate athletes. *American Journal of Sports Medicine* **19,** 76–81.

Kofotolis, N.D., Kellis, E. & Viachopoulos, S.P. Ankle sprain injuries and risk factors in amateur soccer players during a 2-year period. *American Journal of Sports Medicine* **35,** 458–466.

Koh, J. & Dietz, J. (2005) Osteoarthritis in other joints (hip, elbow, foot, ankle, toes, wrist) after sports injuries. *Clinics in Sport Medicine* **24,** 57–70.

Kucera, K.L., Marshall, S.W., Kirkendall, D.T. Marchak, P.M. & Garrett, W.E., Jr. (2005) Injury history as a risk factor for incident injury in youth soccer. *British Journal of Sport Medicine* **38,** 462–466.

Larsen, E., Jensen, P. & Jensen, P. (1999) Long term outcomes of knee and ankle injuries in elite football. *Scandinavian Journal of Medicine and Science in Sport* **9,** 286–289.

Larsen, M., Pearl, A.J., Jaffet, R. & Rudawsky A. (1996) Soccer. In *Epidemiology of Sport Injury* (Caine, D.J., Caine, C.G., & Lindner, K.J., eds.), Human Kinetics, Champaign, IL, pp. 387–398.

LeGall, F., Reilly, T., Vandewalle, H., Church, J. & Rochcongar, P. (2006) Incidence of injuries in elite French youth soccer players. *American Journal of Sports Medicine* **34**: 928–938.

Lohmander, L.S. (2004) Long-term risks for knee osteoarthritis in soccer. In *International Football (Soccer) and Sports Medicine* (Mandelbaum B. & Doe J., eds.), American Orthopaedic Society for Sports Medicine and Federation Internationale de Football Association Medical Assessment and Research Centre, Sage Publications, Thousand Oaks, CA.

Luthje, P., Nurmi, I., Kataja, M., Belt, E., Helenius, P., Kaukonen, J.P., Kiviluoto, H., Kokko, E., Lehtipuu, T.P., Liukkonen, T., Myllyniemi, J., Rasilainen, P., Tolvanen, E., Virtanen, H. & Wallden, M. (1996) Epidemiology and traumatology of injuries in elite soccer: a prospective study in Finland. *Scandinavian Journal of Medicine & Science in Sports* **6,** 180–185.

Maehlum, S., Daljord, O. & Hansen, K.J. (1999) Frequency of injuries in youth soccer. *Medicine & Science in Sports and Exercise* **31**: S401.

Mandelbaum, B.R., Silvers, H.J., Watanabe, D.S., Knarr, J.F., Thomas, S.D., Griffin, L.Y., Kirkendall, D.T. & Garrett, W. Jr. (2005) Effectiveness of neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: 2-year follow-up. *American Journal of Sports Medicine* **33,** 1003–1010.

McAllister, J.R. (2007) *Economic evaluation of an injury prevention strategy in high school basketball.* Dissertation, University of Calgary), University of Calgary, Calgary, AB, Canada. pp. 33–56.

McGuine, T.A. & Keene, J.S. (2006) The effect of a balance training program on the risk of ankle sprains in high school athletes. *American Journal of Sports Medicine* **34,** 1103–1111.

Meeuwisse, W.H. (1991) Predictability of sports injuries: what is the epidemiological evidence? *Sports Medicine* **12,** 8–15.

Meeuwisse, W. (1994) Assessing causation in sport injury: a multifactorial model. *Clin J Sport Med* **4(3)**, p. 166–170.

Meeuwisse WH, Hagel BE, Emery CE and Tyreman H. (2007) A Dynamic Model of Etiology in Sport Injury: The recursive nature of risk and causation. *Clin J Sport Med* **17(3)**, 215–219.

Mihata, L.C.S., Beuteur, A.I. & Boden, B.P. (2006) Comparing the incidence of anterior cruciate ligament injury in collegiate lacrosse, soccer, and basketball players. *American Journal of Sports Medicine* **34,** 899–904.

Moller-Nielsen, J. & Hammar, M. (1989) Women's soccer injuries in relation to the menstrual cycle and oral contraceptive use. *Medicine & Science in Sports & Exercise* **21,** 126–129.

Must, A., Jacques, P.F., Dallal, G.E., Bajema, C.J., & Dietz, W.H. (1992) Long term morbidity and mortality of overweight adolescents: a follow-up of the Harvard Growth Study of 1922 to 1935. *New England Journal of Medicine* **327,** 1350–1355.

Myklebust, G. & Bahr, R. (2005) Return to play guidelines after anterior cruciate ligament injury. *British Journal of Sport Medicine* **39,** 127–131.

Myklebust G., Maehlum, S., Holm, I. & Bahr, R. (1998) A prospective cohort study of anterior cruciate ligament injuries in elite Norwegian team handball. *Scandinavian Journal of Medicine & Science in Sports* **8,** 149–153.

Myer, G.D., Ford, K.R., Brent, J.L. & Hewett, T.E. (2006) The effects of plyometric vs. dynamic stabilization and balance training on power, balance, and landing forces in female athletes. *Journal of Strength and Conditioning Research* **20,** 345–353.

Myer, G.D., Ford, K.R., Palumbo, J.P. & Hewett, T.E. (2005) Neuromuscular training improves performance and lower extremity biomechanics in female athletes. *Journal of Strength and Conditioning Research* **19,** 51–60.

National Centre for Catastrophic Sport Injury Research (2007) Annual survey of catastrophic football injuries. http://www.unc.edu/depts/nccsi [accessed on July 29, 2008]

Nielsen, A. & Yde, J. (1989) Epidemiology and traumatology of injuries in soccer. *American Journal of Sports Medicine* **17**, 803–807.

Nieto, F.J., Szklo, M. & Comstock, G.W. (1993) Childhood weight and growth rate as predictors of adult mortality. *American Journal of Epidemiology* **136,** 201–213.

Olsen, L., Scanlan, A., MacKay, M., Babul, S., Reid, R., Clark, M. & Raina, P. (2004) Strategies for prevention of soccer related injuries: a systematic review. *British Journal of Sports Medicine* **38,** 89–94.

Orchard, J., Marsden, J., Lord, S. & Garlick, D. (1997) Preseason hamstring muscle weakness associated with hamstring muscle injury in Australian footballers. *American Journal of Sports Medicine* **25,** 81–85.

Ostenberg, A. & Roos, H. (2000) Injury risk factors in female European football: a prospective study of 123 players during one season. *Scandinavian Journal of Medicine and Science in Sport* **10,** 279–285.

Paffenbarger, R.S., Kamput, J.B. & Lee, I.M. (1994) Changes in physical fitness and other lifestyle patters influence longevity. *Medicine & Science in Sports and Exercise* **26,** 857–865.

Peterson, L., Junge, A., Chomiak, J., Graf-Baumann, T., & Dvorak, J. (2000) Incidence of football injuries and complaints in different age groups and skill-level groups. *American Journal of Sports Medicine* **28**, S51–S57.

Pollard, C.D., Sigward, S.M., Ota, S., Langford, K. Powers, C.M. (2006) The influence of in-season prevention training on lower-extremity kinematics during landing in female soccer players. *Clinical Journal of Sport Medicine* **16,** 223–227.

Poulsen, T., Freund, K. & Sandvej, K. (1991) Injuries in high-skilled and low skilled soccer: a prospective study. *British Journal of Sports Medicine* **25,** 151–153.

Roos, H., Lauren, M. & Adalberth, T. (1998) Knee osteoarthritis after meniscectomy: prevalence of radiographic changes after twenty-one years, compared with matched-controls. *Arthritis and Rheumatism* **41,** 687–693.

Roos, E.W. (2005) Joint injury causes osteoarthritis in young adults. *Current Opinions in Rheumatology* **17,** 195–200.

Schwebel, D.C., Banaszek, & M.M. McDaniel M. (2007) Behavioural risk factors for youth soccer (football) injury. *Journal of Pediatric Psychology* **32,** 411–416.

Shultz, S.J., Sanders, T.C., Kirk, S.E. & Perrin, D.H. (2005) Sex differences in knee joint laxity change across the female menstrual cycle. *Journal of Sports Medicine & Physical Fitness* **45,** 594–603.

Soderman, K., Alfredson, H., Pietila, T. & Werner, S. (2001) Risk factors for leg injuries in female soccer players: a prospective investigation during one outdoor season. *Knee Surgery Sports Traumatology and Arthroscopy* **9,** 313–321.

Soderman, K., Werner, S., Pietila, T., Engstrom, B. & Alfredson, H. (2000) balance board training: prevention of traumatic injuries of the lower extremity in female soccer players? A prospective randomized intervention study. *Knee Surgery Sports Traumatology & Arthroscopy* **8,** 356–363.

Steffen, K. (2008) Introduction. In K. Steffen *Injuries in female youth football: prevention performance and risk factors.* Dissertation, Norwegian School of Sport Sciences, Oslo Sport Trauma Research Centre, Oslo, Norway, pp. 1–30.

Steffen, K., Andersen, T.E. & Bahr, R. (2007) Risk of injury on artificial turf and natural grass in young female football players. *British Journal of Sport Medicine* 41(suppl.), i33–i37.

Steffen, K., Andersen, T.E. & Bahr R. (2008) Self-reported injury history and lower limb function as risk factors for injuries in female youth players. *American Journal of Sport Medicine* **36,** 700–708.

Surve, I., Schwellnus, M.P., Noakes, T., & Lombard, C. (1994) A fivefold reduction in the incidence of recurrent ankle sprains in soccer players using the sport-stirrup orthosis. *American Journal of Sports Medicine* **22,** 601–606.

Taimela, S., Osterman, K. Kujala, U. (1990) Motor ability and personality with reference to soccer injuries. *Journal of Sport Medicine and Physical Fitness* **30,** 194–201.

Tropp, H., Askling, C. & Gillquist, J. (1985) Prevention of ankle sprains. *American Journal of Sports Medicine* **13,** 259–262.

Tropp, H., Askling, C. & Gillquist, J. (1985) Prevention of ankle sprains. American Journal of Sports Medicine 13:259-262.

Tscholl, P., O'Riordan, D., Fuller, C., Dvorak, J., Gutzwiller, F. & Junge, A. (2007a) Causation of injuries in female football players in top-level tournaments. *British Journal of Sports Medicine* **41**(suppl. 1), i8–i14.

Tscholl, P., O'Riordan, D., Fuller, C., Dvorak, J. & Junge, A. (2007b) Tackle mechanisms and match characteristics in women's elite football tournaments. *British Journal of Sports Medicine* **41**(suppl. 1), i15–i19.

von Prat, A., Roos, E.M. & Roos, H. (2004) High prevalence of osteoarthritis 14 years after ACL tear in male soccer players—a study of radiographic and patient relevant outcomes. *Annals of Rheumatological Disease* **63,** 269–273.

Walden, M., Hagglund, M. & Ekstrand, J. (2005) UEFA Champions League study: a prospective study of injuries in professional football during the 2001–2001 season. *British Journal of Sports Medicine* **39,** 542–546.

Walden, M., Hagglund, M. & Ekstrand, J. (2007) Football injuries during European Championships 2004–2005. *Knee Surgery, Sports Traumatology, Arthroscopy* **15,** 1155–1162.

Witrouw, E., Danneels, L., Asselman, P., D'Have, T. & Cambier, D. (2003) Muscle flexibility as a risk factor for developing muscle injuries in male professional soccer players. *American Journal of Sports Medicine* **31,** 41–46.

Wojtys, E.M., Huston, L.J., Boynton, M.D., Spindler, K.P. & Lindenfeld, T.N. (2002) The effects of the menstrual cycle on anterior cruciate ligament injuries in women as determined by hormone levels. *American Journal of Sports Medicine* **30,** 182–188.

Chapter 18

Softball

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Introduction

The purpose of this chapter is to critically examine the literature reporting injury rates and potential risk factors in softball. We also discuss and suggest possible prevention measures and directions for future investigation.

There are two types of softball – slow-pitch and fast-pitch. Slow-pitch softball is a hugely popular sport, enjoyed by millions of recreational athletes in the United States as a weekend pastime. In addition, fast-pitch softball is also a popular and highly competitive sport for women at the club, high-school, collegiate, and Olympic levels. The difference lies in the pitching style and ball speeds, which are much higher in fast-pitch (Figure 18.1). Young women who play fast-pitch softball in high school—and boys who play baseball—often transition into slow-pitch recreational leagues in adult life. Little is known about this transition and the epidemiology of injury in these recreational leagues.

Although the rules and many elements of the game are very similar between fast-pitch and slow-pitch softball, the stresses imposed on the athletes (especially the pitchers) are quite different. Early epidemiologic research in softball—studies published in the 1980s—largely addressed slow-pitch and consequently had a focus on sliding-related injuries (Meyers et al. 2001). This early softball literature includes some of the most thorough

Figure 18.1 The fast-release under arm pitching style used in fast-pitch softball places significant stress on the shoulder and upper arm. © IOC.

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intervention trials ever done in sports medicine (Janda et al. 1988).

As fast-pitch softball became more popular, the kinetic energies exchanged during on-field injury events in softball increased (Meyers et al. 2001), as did the biomechanical forces on pitchers' arms and shoulders (Werner et al. 2005). This has led to the need for additional research, particularly on interventions to prevent softball injury, that remains largely unmet at this point (Meyers et al. 2001). In fact, the current line of softball research has retreated from the early groundbreaking work on safety bases, becoming increasingly diffuse and descriptive in nature.

Softball is a popular sport that is widely played in the United States and throughout the world. Over 16,600 women played collegiate (fast-pitch) softball in the 2005–2006 academic year, making it the fourth most popular college sport for women, based on the number of participants (National Collegiate Athletic Association 2007). Fast-pitch softball is also the fourth most popular sport for girls at the high-school level (based on the number of participants), with over 373,000 participants (National Federation of State High School Associations 2007). Beyond the high-school and college settings, many more people play recreational slow-pitch and competitive fast-pitch softball in youth and adult leagues. The Sporting Goods Manufacturers Association (2007) reports there were a total of 10.5 million frequent, regular, and casual softball participants in 2006. For the purposes of comparison, baseball has 16.1 million frequent/regular/casual participants (Sporting Goods Manufacturers Association 2007). Thus, baseball accounts for approximately two thirds of participants in the batted-ball sports, with softball contributing the remaining one third.

Softball was invented in 1887 by George Hancock. Originally called mushball or kittenball, the name "softball" was not coined until the 1920s. The sport was originally played by men and did not become popular with women until the formation of the Amateur Softball Association of America in the 1930s. The sport gradually spread throughout the world, fueled in part by the enthusiasm of deployed American servicemen during World War II, eventually leading to the formation of the International Softball Federation in 1965. Fast-pitch softball for women was admitted to the Olympics from 1996 to 2008.

Despite the popularity of fast-pitch and slow-pitch softball, we located very few recent epidemiologic studies that specifically addressed softball. In particular, there are no recent epidemiologic studies of recreational softball participants and younger softball players (high-school age and younger). There are also no prospective studies identifying risk factors for softball injury and no recent evaluations of injury prevention programs in slow-pitch or fast-pitch softball. Finally, review of the literature is complicated by the fact that some studies fail to clearly distinguish between slow-pitch and fast-pitch softball (Pollack et al. 2005).

Who Is Affected by Injury?

National data from the Centers for Disease Control and Prevention on emergency department (ED)–attended sports injuries provides some insight into the significance of softball injury on a population basis. For girls 15 to 19 years of age, softball is the fourth most common sports activity resulting in an ED-attended injury (Centers for Disease Control and Prevention 2002). By comparison, the most common activities resulting in ED-attended injury for girls 15 to 19 years are basketball, gymnastics, and soccer (Centers for Disease Control and Prevention 2002).

From 10 through to 44 years of age, softball is consistently one of the top five activities resulting in sports-related injuries resulting in ED visits for female participants. Across all age groups, softball accounts for 5% of sports-related injuries resulting in ED visits for female participants. For male participants, it is one of the top five activities resulting in a sports-related injury resulting in an ED visit in the 25-to-44-year age group (Centers for Disease Control and Prevention 2002). However, these national data on ED-attended injuries cannot be used to estimate injury incidence, since they do not include data on the number of softball participants at risk. Nevertheless, it is clear that softball injuries in girls and women have considerable public health

Table 18.1 Injury risks and rates in softball.

Study	Design	Age Group	Duration	No. of Participants	No. of Injuries	Risk/1,000 Athletes	Rate/1,000 Athlete-Exposures	Year Data Collected
McLain & Reynolds 1989	Prospective	High school	1 yr	54	9	1.30	—	1987–1988 academic year
DuRant, 1992	Prospective	High school	1 yr	99	9	0.91	—	1990
Powell & Barber-Foss 1999	Prospective	High school	3 yr	—	910	1.67	5.9 (game) 2.7 (practice) 3.5 (overall)	1995–1997 academic year
Radelet et al. 2002	Prospective	Community	2 yr	—	37	—	0.11 (game) 0.07 (practice) 0.10 (overall)	1999–2000 seasons
Knowles et al. 2006	Prospective	High school	3 yr	829	71	—	0.96 (overall)	1996–1999 academic year
Marshall et al. 2007	Prospective	College	16 yr	—	5336	—	4.30 (game) 2.67 (practice)	1988–1989 through 2003–2004 academic year
Rechel et al. 2008	Prospective	High school	1 yr	—	153	—	1.78 (game) 0.79 (practice) 1.13 (overall)	2005–2006 academic year

significance—of a magnitude comparable to that for soccer and basketball.

The epidemiologic studies that met our criteria—quantify both the number of softball injuries and the size of the population at risk—for providing a reliable incidence estimate are listed in Table 18.1. For two of these studies, the data are nearly 20 years old (DuRant 1992; McLain & Reynolds 1989). They are included in Table 18.1 in the interest of completeness, but will not be discussed further.

High-school data from the Reporting Injury Online system based at Nationwide Children's Hospital indicates an overall injury rate of 1 per 1,000 athlete-exposures (AEs) in high-school (fast-pitch) softball (Rechel et al. 2008). This agrees well with much-older high-school data from North Carolina (Knowles et al. 2006). The incidence estimates from a previous National Athletic Trainers Association (NATA) sponsored national high school injury surveillance system (Powell & Barber-Foss 1999) were much higher, for reasons that are unknown.

In relation to other high-school sports, two of the three high-school studies agreed that softball has the lowest injury rate (per 1,000 AEs) of all girls' sports that have been studied. These include volleyball, soccer, basketball (Knowles et al. 2006; Rechel et al. 2008) track and cheerleading (Knowles et al. 2006). The third high school study reported that volleyball had a much lower injury rate than softball (Powell & Barber-Foss 1999).

At the college level, softball has the lowest game injury rate, and the fourth lowest practice injury rate, of the 16 sports monitored by the National Collegiate Athletic Association (NCAA) (Hootman et al. 2007). Based on the college data, base runners account for over one fourth of the injuries in fast-pitch softball (29%), followed by basemen (14%), batters (13%), pitchers (11%), catchers (9%), and shortstops (7%) (Marshall et al. 2007).

The injury rate in community league slow-pitch softball appears to be about one tenth the rate in high school fast-pitch, based on a study of community-based sports in the greater Pittsburgh area in children 7 to 13 years of age (Radelet et al. 2002). On the other hand, the injury rate in fast-pitch softball is two to three times higher at the college level (Marshall et al. 2007) than at the high-school level.

Where Does Injury Occur?

Anatomical Location

The frequency of injury to various anatomical locations is summarized in Table 18.2. The college study (Marshall et al. 2007) and one of the high-school studies (Rechel et al. 2008) disaggregated the data by games and practices, while the other high-school study pooled game and practice data (Powell & Barber-Foss 1999). Irrespective of these methodologic differences, it is clear that the lower extremity is the most commonly injured site, accounting for between 40% and 50% of injuries. This is followed by the upper extremity, accounting for 30% to 40% of injuries.

Rates in Games versus Practices

In college fast-pitch, the rate of injury was 1.6 times higher in games than in practices, although the absolute numbers of game and practices injuries were similar (52% practices and 48% games) (Marshall et al. 2007). Two high-school studies (Powell & Barber-Foss, 1999; Rechel et al. 2008) report a twofold higher rate in games than in practices and agree that the majority of injuries (56% to 65%) occur in practice.

When Does Injury Occur?

Injury Onset

Because of the limited number of studies, there are no data on the proportion of acute versus chronic injuries. It has been reported that very significant biomechanical forces are generated on the arm and shoulder by the "windmill" technique used by fast-pitch pitchers (Werner et al. 2005, 2006) but, surprisingly, the epidemiology of chronic elbow and shoulder conditions has never been studied in these athletes.

Chronometry

There are few published data on chronometry. However, descriptive analysis of NCAA softball data suggests nonsignificant annual decreases in game (−0.2%; $P = 0.74$) and practice (–0.8%;

Table 18.2 Percentage of injuries by body part injured.

Study	Body Part	% of Injuries	
		Game and Practice Combined	
Powell 1999	Head/neck/scalp	3.2	
	Face/scalp	8.0	
	Shoulder/arm	16.3	
	Forearm/wrist/hand	22.9	
	Trunk	5.5	
	Hip/thigh/leg	18.0	
	Knee	10.8	
	Ankle/foot	14.8	
	Other	0.5	
		Game	**Practice**
Marshall et al. 2007	Head/neck	13.4	9.6
	Upper extremity	33.1	33.0
	Truck/back	7.2	12.3
	Lower extremity	43.3	40.8
	Other	3.0	4.4
		Game	**Practice**
Rechel et al. 2008	Head/face/neck	17.1	22.4
	Lower extremity	49.1	35.0
	Upper extremity	32.3	40.7
	Trunk	1.5	1.9
	Lower extremity	49.1	35.0

P = 0.43) injury rates from 1988 to 2004. (Marshall et al. 2007) These numbers suggest that despite advancements in care, softball injury rates remain relatively unchanged. With regard to time in season (preseason, in-season, postseason), this same study suggested injury rates in NCAA softball for preseason practices (3.65 per 1,000 AEs) and in-season games (4.53) were the highest, followed by preseason games (2.65) and postseason games (2.39). In-season (1.68) and postseason (0.81) practices had the lowest injury rates for time of season. (Marshall et al. 2007)

What Is the Outcome?

Injury Type

At the high-school level, sprains and strains are the predominant type of injury, accounting for 40% to 50% of injuries (Table 18.3). At the college level, ankle sprains alone account for one tenth of total injuries (Marshall et al. 2007). In addition, concussions account for 6% of college-game injuries. Fractures of the hand and fingers also account for 6% of college-game injuries.

Note that the college study (Marshall et al. 2007) presented combined body part and injury type combined into a single variable (i.e., this study reported on ankle sprains), whereas body part and injury type have been reported separately for the two high-school studies (i.e., sprain and ankles were disaggregated).

Time Loss

Softball injuries, on average, appear to be similar and perhaps slightly less severe than injuries in other sports, based on the distribution of time lost. The data from Reporting Injury Online at Nationwide Children's Hospital indicates that softball has a smaller proportion of injuries, with a time loss of >3 weeks higher than that of any of the eight other study sports (Rechel et al. 2008), but this difference may simply reflect statistical fluctuation. The previous national high-school study reported that 8% of softball injuries resulted in a time loss

Table 18.3 Percentage of injuries by type of injury.

Study		% of Injuries	
Powell & Barber-Foss 1999	**Injury Type**	**Game and Practice Combined**	
	General trauma	27.6	
	Sprains	23.8	
	Strains	32.2	
	Fractures	8.4	
	Musculoskeletal	3.8	
	Neurotrauma	3.2	
	General Stress	1.0	
Marshall et al. 2007	**Body Part and Injury Type**	**Game**	**Practice**
	Ankle sprain	10.3	9.5
	Knee derangement	8.7	5.4
	Concussion	6.0	2.8
	Upper-leg strain	5.1	8.5
	Hand/digit fracture	5.9	1.6
Rechel et al. 2008	**Injury Type**	**Game**	**Practice**
	Sprains/strains	42.0	43.7
	Contusions	19.1	11.3
	Fractures	18.3	16.6
	Concussions	0.4	8.9

of >3 weeks—the third lowest of the 10 sports studied (Powell & Barber-Foss, 1999). The NCAA study reported that 25% of game injuries and 22% of practice injuries resulted in ⩾10 days of time loss. This was similar to rates for women's soccer, women's lacrosse, volleyball, and women's basketball. Gymnastics had a much greater proportion of injuries resulting in ⩾10 days of time loss (39% of game and 32% of practice injuries), whereas field hockey had a lower proportion (15% of game and 13% of practice injuries). In a study of injury patterns among female high-school athletes, softball resulted in the highest proportion of subsequent injuries, causing ⩾8 days lost, as compared with similar new injuries causing time lost when compared with four other high-schools sports. (Rauh et al. 2007)

Clinical Outcome

A study of reinjuries in girls' high-school sports (Knowles et al. 2007) noted that softball had a lower proportion of multiple injuries (19%) than soccer or basketball (27% and 26%, respectively). This analysis, using the same data reported by Powell and Barber-Foss (1999), demonstrated that tears and ruptures of the anterior cruciate ligament and shoulder rotator-cuff injuries clearly have a high rate of reinjury in softball.

Data on cardiac deaths due to chest-wall impacts have been reported for softball. Maron et al. (1995) reported two deaths over the period 1977 to 1995. One was of a 4-year-old girl and the other was to a 16-year-old boy. Both resulted from recreational play in the family's home or a public park.

Economic Cost

A high-school study from North Carolina reported that the average medical cost, in 1999 U.S dollars, of a high-school softball injury was $416. In total, the average comprehensive cost for high-school softball injury was $5,550 per injury (Knowles et al. 2007). Comprehensive costs include medical costs, loss of earnings, and lost quality of life. Interestingly, the average comprehensive cost of injury in softball was lower than in any of the other 11 sports studied (Knowles et al. 2007).

What Are the Risk Factors?

Risk factors for injury should ideally be identified from analytic studies, typically using prospective cohort or case–control designs. Only a small number of studies have been conducted within the past decade for fast-pitch or slow-pitch prospectively identifying risk factors for injury using correlations or predictive values. Only type of base has been addressed in a series of epidemiologic studies (Janda et al. 1988, 1990, 2001; Sendre et al. 1994) (see "Injury Prevention" section). There is evidence from one study that level of play is an extrinsic risk factor, because injury rates in the NCAA rise slightly with advancement of competitive level. Division I has the highest injury rates (game. 4.45 per 1,000 AEs; practice, 2.98) followed by Division II (game, 4.32; practice, 2.85) and Division III (game, 4.14; practice, 2.28).

What Are the Inciting Events?

Janda (2003) describes three types of inciting events in slow-pitch softball: sliding, collisions, and falls. In addition, injuries related to pitching and throwing are a concern in fast-pitch.

Sliding

In college softball, sliding accounts for 23% of injuries in games, a rate of 0.89 injury per 1,000 AEs. By comparison, sliding accounts for only 13% of baseball injuries, although the rate is approximately similar (0.75 injury per 1,000 AEs). However, there are more slides per game in baseball (7.7) than in softball (5.3) (Hosey & Puffer 2000). Thus, when rates are computed using slides as the denominator, it becomes clear that the sliding-injury rate is twice as high in softball as in baseball (12 injuries per 1,000 slides vs. 6 per 1,000 slides) (Hosey & Puffer 2000).

It is important to note that, in softball, injury rates are higher for head-first slides (19.46 per 1,000 slides) than for feet-first slides (10.04 per 1,000 slides) or divebacks (7.49 per 1,000 divebacks) (Hosey & Puffer 2000). Furthermore, in a high-speed video analysis of 20 college baseball players, it was found that performance (as measured by time to reach the base) was almost identical for feet-first and head-first slides (3.67 seconds for feet-first vs. 3.65 for head-first) (Hosey et al. 2003). Thus, one review of the literature, concluded that feet-first sliding is safer than head-first sliding and has no performance cost to the player (Flyger et al. 2006). Based on this, we would recommend that the baseball studies of sliding performance (Hosey et al. 2003) be replicated in softball and that this line of research be expanded to test the hypothesis that feet-first slides in softball provide an injury-prevention advantage with no performance cost.

The downside to the increased use of the feet-first slide is impact with the base, leading to ankle sprains. In college softball, 9% of all game injuries were due to contact with a fixed (traditional) base, and 43% of all game injuries due to contact with a base were ankle sprains (Marshall et al. 2007). This suggests that increased use of the feet-first slide in combination with increased use of safety bases may be the most effective injury-prevention strategy.

Although 9% of all game injuries were due to contact with a fixed (traditional) base, only 1% of injuries involved contact with a safety base. However, the prevalence of safety bases in college softball is unknown. Collection of data on prevalence of the use of safety bases would be an inexpensive and highly useful means of verifying the injury-prevention capacity of safety bases.

Pitching and Throwing

The pitching technique in softball involves three phases: windup and stride, delivery, and follow-through (Flyger et al. 2006). Arm strength is an important determinant of successful pitching, as is timing, coordination, and contributions from the trunk and rotator muscles (Flyger et al. 2006). Underarm pitching is an ergonomically stressful motion, with high loads on the arm and shoulder during the downward phase of arm swing (Flyger et al. 2006). In windmill pitchers, the loads placed on the elbow and shoulder, and the resulting distraction stress, are comparable to those experienced by baseball pitchers (Werner et al. 2005, 2006).

Stresses on the arm and shoulder due to throwing are also assumed to be significant in softball. Axe et al. (2002) observed 220 half-innings of college softball and reported that pitchers threw an average of 89.61 pitches per game, infielders threw the ball up to 6.30 times per game, and outfielders threw distances of up to 175 feet. Based on their data, the authors developed a series of off-season conditioning/rehabilitative programs. However, the effectiveness of these programs has never been studied.

Contact with Other Players and Objects (Collisions and Falls)

Over half the game injuries in college softball are due to contact with inanimate objects, including balls (14%), the ground (14%), bases (10%), and dugouts, walls, and railings (2%) (Marshall et al. 2007). The use of safety balls and safety bases and padding of walls and railings have the potential to reduce some of these injuries (Meyers et al. 2001).

Injury Prevention

There has been a long-standing interest in the medical community in reducing the risk of injury to children and adolescents playing baseball and softball (American Academy of Pediatrics Committee on Sports Medicine and Fitness 1994). However, as is the case for many sports, the few scientific studies that have focused on the effectiveness of preventive measures and the majority of the interventions that have been suggested have never been evaluated (Table 18.4). The discussion below focuses on three areas that we consider to have particular importance for injury prevention and future research. Note, however, that only safety bases have been proven effective in epidemiologic studies of softball injury. The sections on "Other Equipment Modifications" and "Throwing and Pitching" reflect our informed opinion, drawing on biomechanical research and baseball studies.

Safety Bases

Softball is distinguished by an early series of studies that addressed safety bases (Janda et al. 1988, 1990; Sendre et al. 1994). These studies demonstrated the effectiveness of safety bases, with over 90% of sliding injuries prevented (Table 18.5). It is clear from these studies that the use of safety bases should be encouraged at all levels of the game. It is curious, however, that the line of research addressing safety bases petered out in the 1990s. Typically, a positive evaluation of an effective intervention would generate additional follow-up research, addressing how best to effect behavioral change in an effort to have the intervention adopted by as many users as possible.

These studies are also interesting from a methodologic standpoint. Softball and baseball fields were fitted with the safety bases and teams rotated

Table 18.4 Proposed, promising, and proven interventions for softball injury.

Intervention	Supporting Literature
Proven	
Safety bases	Janda 1990; Janda et al. 1992; Sendre 1994
Promising but Unevaluated	
Throwing and pitching conditioning programs	Meyers et al. 2001; Axe et al. 2002; Flyger et al. 2006
Suggested but Unevaluated	
Coaching and player education	Meyers et al. 2001; Radelet et al. 2002
Padding of walls, backstops, rails, and dugouts	Meyers et al. 2001; Janda 2003
Pitch counts	Werner et al. 2005
Well-maintained fields, facilities, and equipment	Meyers et al. 2001; Janda 2003
Return-to-play guidelines for concussions, neck/back injuries, fractures, and dislocations	Radelet et al. 2002
Reduced-impact balls	Flyger et al. 2006
Face guards	Radelet et al. 2002
Feet-first slides instead of head-first slides	Flyger et al. 2006
Ineffective	
Chest protectors	Flyger et al. 2006

Table 18.5 Safety bases in softball.[a]

Study	Design	Study Population	Base	Study Duration	Injury Data Source	Exposure Data	No. of Sliding Injuries	Proportion of Sliding Injuries Prevented[b]	Study Conclusion
Janda et al. 1988	Controlled trial	Recreational softball league (Ann Arbor summer league), 18–55 yr, men and women	Rogers Break-Away Base	2 yr	Field staff, emergency rooms, student health clinic, orthopedic surgeons	633 games played with breakaway bases; 627 games played with standard bases	2 on breakaway; 45 on traditional	96% (95% CI, 82–99) gRR = 0.04 (95% CI, 0.01–0.18)	"Use of breakaway bases … could potentially achieve a … reduction of injuries."
Janda et al. 1990	Preintervention/ postintervention	Same population as Janda 1988	Rogers Break-Away Base	2 yr	Same as Janda 1988	1035 games played with breakaway bases	2 on breakaway	97% (95% CI, 89–99) gRR = 0.03 (95% ,CI: 0.01–0.11)	"Breakaway bases are …. safer than standard stationary bases."
Sendre et al. 1994	Controlled trial	Recreational softball, collegiate (varsity/junior varsity/intramural) baseball and softball, high-school and club baseball, 15–48 yr, men and women	Hollywood Impact Base	2 yr	Sports medicine personnel and umpires	472 games and 33,153 AEs on Hollywood bases; 155 games and 3,999 AEs on traditional bases	1 on Hollywood; 4 on traditional	92% (95% CI, 27–99) gRR = 0.08 (95% CI, 0.01–0.73)	"Use of the Hollywood Impact Base in baseball and softball significantly reduced the possibility of injury."

AE = athlete-exposure; CI = confidence interval; gRR = game risk ratio.
[a] A similar table appears in Pollack et al (2005).
[b] Defned as 1 – gRR, or 1 – (injury risk per game using safety bases/injury risk per game using traditional bases).

between the fields with traditional bases and the safety bases, so that all teams played on both types of base. However, none of studies describe a procedure for randomizing teams to fields, and none of them provide a clear study definition of a "sliding" injury. In one study (Sendre et al. 1994), the recreational softball teams played on both traditional and safety bases, whereas the college, high-school, and club softball and baseball teams played only on safety bases, creating the potential for confounding by sport and level of competition. The other two studies used games played as the denominator (Janda et al. 1988, 1990), rather than the more nuanced measure of athlete-exposures. Despite these limitations, the studies were highly influential and are widely regarded as landmark publications.

Other Equipment Modifications

Laboratory studies of protective eyewear indicate that polycarbonate lenses provide excellent protection for batters from the risk of being hit in the eye by a pitched ball (Vinger et al. 1997). Two baseball studies have indicated that face guards reduce the risk of facial injury by 23% to 35% (Danis Hu & Bell 2000; Marshall et al. 2003). Reduced-impact balls (also known as safety balls or sof-tee balls) have been found to be effective in preventing injury in youth baseball (Marshall et al. 2003; Pasternack et al. 1996). These balls deform on impact and dissipate the kinetic energy of the ball over a wider area, thereby reducing impact force.

Chest or "heart" protectors are commercially available for batters and fielders. They consist of padding worn over the sternum and chest wall. Although it is claimed that these devices prevent commotio cordis, they appear to be completely ineffective (Viano et al. 2000; Weinstock et al. 2006; Doerer et al. 2007).

Throwing and Pitching

Repeatedly pitching and throwing a softball is an ergonomically stressful activity. Youth pitchers who throw a large number of pitches in a short span of time are potentially at risk of incurring repetitive overuse syndrome (Werner et al. 2005, 2006). Repetitive throwing of the ball also has the potential to induce injury. Pitch-count programs are designed to limit the number of pitches thrown in games and practices by a single individual. A severe limitation of these programs is that they apply only to the number of pitches thrown in a specific setting, such a given league. A child who plays in multiple leagues, or who throws a lot of practice pitches in an informal setting (such as at home), could easily exceed the recommended pitch count.

Further Research

As has been noted by other reviewers (Meyers et al. 2001; Pollack et al. 2005; Flyger et al. 2006) the scientific literature on softball is sporadic and episodic. From a public health perspective, the amount of research effort devoted to softball is woefully insufficient, relative to its overall popularity in the community and at the high school and college level. In particular, there is a dearth of analytical epidemiologic risk-factor studies and rigorous intervention studies addressing injury prevention in softball.

The overwhelming preponderance of the research effort in the batted-ball sports is directed toward baseball, despite that fact that softball accounts for over one third of participants in these two sports combined. Although some of the knowledge gleaned from baseball research can be assumed to be applicable to fast-pitch softball, there are sufficient differences between the games (especially in terms of pitching mechanics) that there is a pressing need for more epidemiologic research on softball.

There are few (if any) epidemiologists conducting research specifically targeting softball injury. We located only one epidemiologic study within the past decade that addressed solely softball (Marshall et al. 2007); however, even this paper was part of a special journal supplement addressing multiple sports. In contrast, three review papers calling for more softball research were published between 2001 and 2006 (Meyers et al. 2002; Pollack et al. 2005; Flyger et al. 2006). It seems that softball has the dubious distinction of having more published calls for epidemiologic research than actual epidemiologic research papers.

It is clear that the current epidemiologic research in this area is limited and needs to be strengthened through additional studies of youth and recreational populations, the use of analytic cohort and case–control studies designed to identify and quantify risk factors for injury, and a return to intervention studies (such as the safety-base studies) evaluating injury-prevention initiatives. Some calls for future research along these lines include those emphasizing the need for descriptive studies and injury surveillance data (Meyer et al. 2001; Pollack et al. 2005), analytic studies aimed at identifying risk factors (Pollack et al. 2005) and specific research initiatives including the effect of surfacing on injury risk (Meyers et al. 2001), conditioning and rehabilitation programs (Meyers et al. 2001; Flyger et al. 2006), the effectiveness of institutional-level injury-prevention programs (Meyers et al. 2001), and the effect of plyometric training programs on injury risk (Flyger et al. 2006).

In addition to the areas for future research identified by previous authors (Table 18.4), there is also a need for a comprehensive prospective cohort study aimed at identifying a variety of intrinsic (e.g., age, skill, sliding technique, pitching mechanisms, physical characteristics) and extrinsic (e.g., experience, level of competition, coach factors, equipment, types of bases used) risk factors. There is a pressing need to study the effect of the stresses placed on the upper extremity by pitching in fast-pitch softball, particularly with a view to the identification of particular movement patterns, pitching styles, or anatomical characteristics of arm and shoulder, that would predispose these athletes to acute or overuse injury.

Research should be done to distinguish the injury differences between slow- and fast-pitch softball. Research should also focus on the recreational slow-pitch population that forms the majority of softball players. Little research exists for the youth population, in which a great number of athletes participate in softball at various levels. There is also a large (>1 million participants) amateur fast-pitch population in the United States—outside the high-school and college settings—that is almost completely understudied. Conditioning programs specific to softball developed for off-season or rehabilitative purposes (Axe et al. 2002) have never been evaluated. Pitch-count limits appear to be successful in baseball (Lyman et al. 2002) but have never been studied in softball. The use of face guards in softball has been recommended (Radelet et al. 2002) but never studied.

Concerns have been noted about the biomechanics of pitching in elite fast-pitch softball. Literature indicates there is excessive distraction at the shoulder as a result of muscle force used to produce delivery of the pitch. (Janda et al. 1992; Loosli et al. 1992; Werner et al. 2005, 2006) This distraction, force, and torque presumably predisposes the softball pitcher to overuse injury, but no prospective cohort studies have been conducted to quantify their incidence of overuse injury. Likewise, sliding mechanics presumably also predispose softball athletes to injury (Corzatt et al. 1984), but has never been addressed in rigorous analytical epidemiologic study such as a prospective cohort study.

Finally, more research on safety interventions is needed. In particular, more research on safety bases is needed, in order to identify who is currently not using them, whether they would benefit from using them, and to identify barriers to adoption of safety bases. It is also important to replicate the studies that demonstrated that the bases were effective in preventing injury (especially since the most recent of those studies is nearly 20 years old). Research on sliding is also needed, with a view to determining whether feet-first slides provide an injury prevention without a performance cost, as has been suggested (Flyger et al. 2006). We suggest that the feet-first slide in combination with the safety base would be an important injury-prevention strategy to target in future research.

References

American Academy of Pediatrics Committee on Sports Medicine and Fitness (1994) Risk of injury from baseball and softball in children 5–14 years of age. *Pediatrics* **93,** 690–692.

Axe, M.J., Windley, T.C. & Snyder-Mackler, L. (2002) Data-based interval throwing programs for collegiate softball players. *Journal of Athletic Training* **37,** 194–203.

Barrentine, S.W., Fleisig, G.S., Whiteside, J.A., Escamilla, R.F. & Andrews, J.R. (1998) Biomechanics of windmill softball pitching with implications about injury mechanisms at the shoulder and elbow. *Journal of Orthopedic and Sports Physical Therapy* **28,** 405–15.

Centers for Disease Control and Prevention (2002) Nonfatal sports and recreation-related injuries treated in

emergency departments-United States, July 2000–June 2001. *Morbidity and Mortality Weekly Report* **51,** 736–740.
Corzatt, R.D., Groppel, J.L., Pfautsch, E. & Boscardin, J. (1984) The biomechanics of head-first versus feet-first sliding. *American Journal of Sports Medicine* **12,** 229–232.
Danis, R.P., Hu, K. & Bell, M. (2000) Acceptability of baseball face guards and reduction of oculofacial injury in receptive youth league players. Injury *Prevention* **6,** 232–234.
Doerer, J.J., Haas, T.S., Estes, N.A., 3rd, Link, M.S. & Maron, B.J. (2007) Evaluation of chest barriers for protection against sudden death due to commotio cordis. *American Journal of Cardiology* **99,** 857–859.
Durant, R.H., Pendergrast, R.A., Seymore, C., Gaillard, G. & Donner, J. (1992) Findings from the preparticipation athletic examination and athletic injuries. *American Journal of Diseases in Children* **146,** 85–91.
Flyger, N., Button, C. & Rishiraj, N. (2006) The science of softball: implications for performance and injury prevention. *Sports Medicine* **36,** 797–816.
Hootman, J.M., Dick, R. & Agel, J. (2007) Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. *Journal of Athletic Training* **42,** 311–319.
Hosey, R.G., Mattacola, C.G. & Shapiro, R. (2003) High-speed video analysis of head-first and feet-first sliding techniques in collegiate baseball players. *Clinical Journal of Sports Medicine* **13,** 242–244.
Hosey, R.G. & Puffer, J.C. (2000) Baseball and softball sliding injuries: incidence, and the effect of technique in collegiate baseball and softball players. *American Journal of Sports Medicine* **28,** 360–363.
Janda, D.H. (2003) The prevention of baseball and softball injuries. *Clinical Orthopaedics and Related Research* **409,** 20–28.
Janda, D.H., Bir, C. & Kedroske, B. (2001) A comparison of standard vs. breakaway bases: an analysis of a preventative intervention for softball and baseball foot and ankle injuries. *Foot and Ankle International* **22,** 810–816.
Janda, D.H., Wild, D.E. & Hensinger, R.N. (1992) Softball injuries: aetiology and prevention. *Sports Medicine* **13,** 285–291.
Janda, D.H., Wojtys, E.M., Hankin, F.M., Benedict, M.E., & Hensinger, R.N. (1990) A three-phase analysis of the prevention of recreational softball injuries. *American Journal of Sports Medicine* **18,** 632–635.
Janda, D.H., Wojtys, E.M., Hankin, F.M. & Benedict, M.E. (1988) Softball sliding injuries: a prospective study comparing standard and modified bases. *Journal of the American Medical Association* **259,** 1848–1850.
Knowles, S.B., Marshall, S.W., Bowling, J.M., Loomis, D., Millikan, R., Yang, J., Weaver, N.L., Kalsbeek, W. & Mueller, F.O. (2006) A prospective study of injury incidence among North Carolina high school athletes. *American Journal of Epidemiology* **164,** 1209–1221.
Knowles, S.B., Marshall, S.W., Miller, T., Spicer, R., Bowling, J.M., Loomis, D., Millikan, R.W., Yang, J. & Mueller, F.O. (2007) Cost of injuries from a prospective cohort study of North Carolina high school athletes. *Injury Prevention* **13,** 416–521.
Loosli, A.R., Requa, R.K., Garrick, J.G. & Hanley, E. (1992) Injuries to pitchers in women's collegiate fast-pitch softball. *American Journal of Sports Medicine* **20,** 35–37.
Lyman, S., Fleisig, G.S., Andrews, J.R. & Osinski, E.D. (2002) Effect of pitch type, pitch count, and pitching mechanics on risk of elbow and shoulder pain in youth baseball pitchers. *American Journal of Sports Medicine* **30,** 463–468.
Maron, B.J., Poliac, L.C., Kaplan, J.A. & Mueller, F.O. (1995) Blunt impact to the chest leading to sudden death from cardiac arrest during sports activities. *New England Journal of Medicine* **333,** 337–342.
Marshall, S.W., Hamstra-Wright, K.L., Dick, R., Grove, K.A. & Agel, J. (2007) Descriptive epidemiology of collegiate women's softball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988–1989 through 2003–2004. *Journal of Athletic Training* **42,** 286–294.
Marshall, S.W., Mueller, F.O., Kirby, D.P. & Yang, J. (2003) Evaluation of safety balls and faceguards for prevention of injuries in youth baseball. *Journal of the American Medical Association* **289,** 568–574.
McLain, L.G. & Reynolds, S. (1989) Sports injuries in a high school. *Pediatrics* **84,** 446–50.
Meyers, M.C., Brown, B.R. & Bloom, J.A. (2001) Fast pitch softball injuries. *Sports Medicine* **31,** 61–73.
National Collegiate Athletic Association. (2007) *NCAA Sports Sponsorship and Participation Rates Report*. National Collegiate Athletic Association, Indianapolis, IN.
National Federation of State High School Associations (2007) 2005–2006 *High school athletics participation survey.* National Federation of State High School Associations, Indianapolis, IN.
Pasternack, J.S., Veenema, K.R. & Callahan, C.M. (1996) Baseball injuries: a Little League survey. *Pediatrics* **98,** 445–448.
Pollack, K.M., Canham-Chervak, M., Gazal-Carvalho, C., Jones, B.H. & Baker, S.P. (2005) Interventions to prevent softball related injuries: a review of the literature. *Injury Prevention* **11,** 277–281.
Powell, J.W. & Barber-Foss, K.D. (1999) Injury patterns in selected high school sports: a review of the 1995–1997 seasons. *Journal of Athletic Training* **34,** 277–284.
Radelet, M.A., Lephart, S.M., Rubinstein, E.N. & Myers, J.B. (2002) Survey of the injury rate for children in community sports. *Pediatrics* **110,** e28.
Rauh, M.J., Macera, C.A., Ji, M. & Wiksten, D.L. (2007) Subsequent injury patterns in girls' high school sports. *Journal of Athletic Training* **42,** 486–494.
Rechel, J.A., Yard, E.E. & Comstock, R.D. (2008) An epidemiologic comparison of high school sports injuries sustained in practice and competition. *Journal of Athletic Training* **43,** 197–204.
Sendre, R.A., Keating, T.M., Hornak, J.E. & Newitt, P.A. (1994) Use of the Hollywood Impact Base and standard stationary base to reduce sliding and base-running injuries in baseball and softball. *American Journal of Sports Medicine* **22,** 450–453.
Sporting Goods Manufacturers Association. (2007) *SGMA 2007 Sports and Fitness Participation Report*. Sporting Good Manufacturers Association, Washington, DC.
Viano, D.C., Bir, C.A., Cheney, A.K. & Janda, D.H. (2000) Prevention of commotio cordis in baseball: an evaluation of chest protectors. *Journal of Trauma* **49,** 1023–1028.
Vinger, P.F., Parver, L., Alfaro, D.V., 3rd, Woods, T. & Abrams, B.S. (1997) Shatter resistance of spectacle lenses. *Journal of the American Medical Association* **277,** 142–144.
Weinstock, J., Maron, B.J., Song, C., Mane, P.P., Estes, N.A., 3rd & Link, M.S. (2006)

Failure of commercially available chest wall protectors to prevent sudden cardiac death induced by chest wall blows in an experimental model of commotio cordis. *Pediatrics* **117,** e656–e662.

Werner, S.L., Guido, J.A., Mcneice, R.P., Richardson, J.L., Delude, N.A. & Stewart, G.W. (2005) Biomechanics of youth windmill softball pitching. *American Journal of Sports Medicine* **33,** 552–560.

Werner, S.L., Jones, D.G., Guido, J.A., Jr. & Brunet, M.E. (2006) Kinematics and kinetics of elite windmill softball pitching. *American Journal of Sports Medicine* **34,** 597–603.

Chapter 19

Taekwondo

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Introduction

Taekwondo is a modern sport that originated in Korea in the 1950s. It was based on Japanese karate using non-contact rules for competition (Capener 1995) and was internationally unified under the International Taekwondo Federation in 1966. In 1973, a full-contact version eventually emerged in Korea under the banner of the World Taekwondo Federation (WTF). It is this form of taekwondo that appears at the Olympic Games.

The purpose of this chapter was to review injuries in adult taekwondo athletes according to WTF rules. For a review of taekwondo injuries in youth, children and adolescents, see Pieter (2005).

Who is affected by injury?

Table 19.1 shows comparative competition injury rates per 1,000 athlete exposures (A-E) in adult *taekwondo-in* (taekwondo athletes). An injury was defined as any circumstance for which the athlete sought the assistance of the on-site medical personnel, while a time-loss injury was defined as one that prevented the competitor from completing the present bout or subsequent bouts or both, and from participating in taekwondo for a minimum of 1 day thereafter. *Elite* is defined as competing at the (inter)national level, while *recreational* is anything below national. One A-E refers to one athlete being exposed to the possibility of incurring an injury when engaged in a bout.

Perusal of Table 19.1 indicates that most of the injuries in taekwondo competition in adults are not serious—that is, do not lead to time away from practice or competition. The total competition injury rate for men ranges from 20.6 to 139.5 per 1,000 A-E, while their time-loss injury rate ranges from 6.9 to 33.6 per 1,000 A-E. For women, the total injury rate ranges from 25.3 to 105.5 per 1,000 A-E, while their time-loss injury rate ranges from 2.4 to 23.8 per 1,000 A-E.

Where does injury occur?

Anatomical location

The prospective studies included in Table 19.2 indicate the lower extremities to be the body region injured most often in taekwondo competition for all reported injuries, which is consistent with the almost exclusive use of kicking techniques in competition and training. The range of the percent distribution of all reported injuries to the lower extremities is from 0.0% to 45.7% in men and from 50.0% to 100.0% in women. The instep of the foot is especially susceptible to injury (Pieter & Zemper 1995; Kazemi & Pieter 2004).

What is of more concern, however, is that in competition, the head-and-neck area is the second most frequently injured body region, with 22.2% to 75.0% of all reported injuries in men and 7.9% to 25.3% in women (Table 19.2).

In a prospective training study by Kim et al. (1994), the lower limbs were reported to be the

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Table 19.1 Distribution of injury rates per 1,000 athlete-exposures (95% confidence interval) in adults.

Study	Study Design	Level	Competition	Sample Size	Total Injury Rate[a]	Time-Loss Injury Rate[b]
Zemper & Pieter (1989)	P	Elite	Team Trials	M = 48 F = 48	127.4 (79.3–175.4) 90.1 (50.6–129.6)	23.6 (5.1–52.3) 13.5 (1.8–28.8)
Pieter & Lufting (1994)	P	Elite	World Championship	M = 273 F = 160	—	22.9 (9.9–35.9) 9.7 (1.3–20.6)
Pieter (1995)	P	Elite	National Championships	M = 1,665 F = 742	—	33.5 (27.3–39.6) 23.0 (15.7–30.4)
Pieter et al. (1995)	P	Elite	European Cup	M = 67 F = 30	139.5 (94.0–185.1) 96.5 (39.5–153.5)	27.1 (7.0–47.2) 8.8 (8.4–26.0)
Pieter et al. (1998)[a]	P	Recreational	Open tournament	M = 46	51.3 (1.0–101.5)	25.6 (9.9–61.2)
Pieter & Bercades (1997)[b]				F = 24	47.6 (18.4–113.6)	23.8 (22.9–70.5)
Pieter & Zemper (1999)	P	Elite	National Championships	M = 1,665 F = 742	95.1 (84.7–105.4) 105.5 (89.8–121.1)	—
Koh et al. (2001)	P	Elite	World Championship	M = 330 F = 233	120.8 (92.9–148.7) 90.1 (61.4–118.7)	33.6 (18.9–48.3) 14.22 (2.8–25.6)
Beis et al. (2001b)[a]	P	Elite	National Championship	M = 533	20.6 (11.8–29.3)	6.9 (1.8–11.9)
Beis et al. (2007)[b]				F = 216	36.4 (18.0–54.8)	2.4 (2.3–7.2)
Kazemi & Pieter (2004)	P	Elite	National Championship	M = 219 F = 99	79.9 (53.4–106.4) 25.3 (3.2–47.4)	—

F = female; M = male; P = prospective.
[a] Any circumstance for which the athlete sought treatment from the on-site medical personnel.
[b] Any injury that prevented the competitor from completing the present bout or subsequent ones or both and from participating in taekwondo for a minimum of 1 day thereafter.

body region most often affected, followed by the trunk. In a retrospective study, Kazemi et al. (2005) confirmed the lower extremities (46.5% of all injuries) to be most often injured in taekwondo training, followed by the upper extremities (18.0%) as did Zetaruk et al. (2005) in their retrospective training study on time-loss injuries: 57.1% and 40.8% for the lower and upper extremities, respectively.

Environmental location

The literature search revealed that most studies included all reported taekwondo injuries that occurred at competitions. Few are available on such injuries sustained during training.

When does injury occur?

Injury onset

Most analyses of taekwondo injuries have been concerned with acute injuries, and few studies have detailed a gradual onset of taekwondo competition injuries. For instance, Pieter and Zemper (1999) reported gradual onset of injuries in both men (0.6 per 1,000 A-E; 95% confidence interval [CI], 0.2–1.4) and women (0.6 per 1,000 A-E; 95% CI, 0.6–1.8). Information implicated in the gradual onset of competition injuries, such as frequency, duration, and intensity of training, however, is lacking (Ohta-Fukushima et al. 2002).

Table 19.2 Percent distribution of all reported injuries by location in *taekwondo-in*.[a]

	Zemper & Pieter (1989)		Pieter et al. (1995)		Pieter et al. (1998)		Pieter & Zemper (1999)		Koh et al. (2001)		Beis et al. (2001)		Kazemi & Pieter (2004)	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F
Total no. of injuries	27	20	36	11	4	2	324	174	71	38	21	15	35	5
Head and neck M, 24.9 (20.9–29.3) F, 17.2 (12.5–21.9)	**22.2**	**20.0**	**33.3**	**9.1**	**75.0**	**50.0**	**30.3**	**25.3**	**23.9**	**7.9**	**33.3**	**13.3**	**34.3**	**—**
—Head	3.7	5.0		—	25	—	7.4	2.9	8.5	5.3	—	—	8.6	
—Face	3.7	5.0		—	—	—	7.4	4.6	2.8	—	4.8	6.7	2.9	
—Mouth	7.4	—		—	—	—	4.6	4.0	—	—	4.8	—	2.9	
—Nose	3.7	—		—	—	—	3.7	6.9	4.2	—	14.3	6.7	8.6	
—Other	3.7	10.0		9.1	50.0	50.0	7.2	6.9	8.5	2.6	9.5	—	11.4	
Trunk M, 9.0 (6.6–11.4) F, 4.3 (2.0–6.6)	**11.1**	**—**	**8.3**	**18.2**	**—**	**—**	**11.1**	**4.6**	**7.0**	**6.7**	**14.3**	**6.7**	**17.1**	**—**
—Ribs	7.4		—				2.8	1.2	—	—	—	6.7	—	
—Pelvis/hips	—		2.8				2.2	—	5.6	—	—	—	2.9	
—Groin	—		2.8	18.2			2.2	1.2	—	—	9.5	—	—	
—Other	3.7		2.8				3.9	2.2	1.4	6.7	4.8	—	14.3	
Upper extremities M, 11.0 (8.4–13.7) F, 14.2 (10.0–18.5)	**22.2**	**—**	**—**	**9.1**	**25.0**	**—**	**12.0**	**15.5**	**26.8**	**46.8**	**19.1**	**13.3**	**8.6**	**—**
—Hands	14.8			—	—	—	4.9	7.5	5.6	6.7	—	—	8.6	
—Fingers	3.7			—	25.0	—	2.8	2.9	11.3	6.7	14.3	13.3	—	
—Wrist	—			—	—	—	1.8	1.2	2.8	6.7	4.8	—	—	
—Other	3.7			9.1	—	—	2.5	3.9	7.0	26.7	—	—	—	
Lower extremities M, 44.2 (38.1–48.7) F. 53.0 (44.6–61.2)	**44.4**	**80.0**	**41.7**	**63.6**	**—**	**50.0**	**45.7**	**52.3**	**42.3**	**71.1**	**33.3**	**66.7**	**40.0**	**100**
—Foot	18.5	40.0	25.0	9.1	—	—	16.4	19.5	16.9	26.3	9.5	40.0	11.4	60.0
—Lower leg	11.1	5.0	8.3	27.3	—	—	4.4	11.5	8.5	13.2	9.5	—	5.7	—
—Knee	11.1	15.0	—	—	—	50.0	9.0	4.0	9.9	10.5	4.8	13.3	—	—
—Upper leg	—	15.0	8.3	27.3	—	—	2.8	2.9	5.6	5.3	—	6.7	—	—
—Other	3.7	5.0	—	—	—	—	13.1	14.4	1.4	15.8	9.5	6.7	22.9	40.0
Other	**—**	**—**	**—**	**—**	**—**	**—**	**—**	**1.2**	**—**	**—**	**—**		**—**	**—**

F = females; M = males.

[a] Injury rates per 1,000 athlete-exposures (95% CI) for all studies combined.

Chronometry

Only Beis et al. (2001a) have reported the time during competition when an injury occurred. They found that rates were highest in the preliminary rounds and decreased as competition progressed. Specifically, men incurred 52.3% of all injuries in the first match (10.8 per 1,000 A-E; 95% CI, 4.4–17.1), followed by 23.8% (4.9 per 1,000 A-E; 95% CI, 0.6–9.2) in the semifinals, and 19.1% (3.9 per 1,000 A-E; 95% CI, 0.1–7.8) in the finals.

The women sustained 33.3% of all injuries in the first match (12.1 per 1,000 A-E; 95% CI, 1.5–22.8), followed by 26.7% in the semifinals (9.7 per 1,000 A-E; 95% CI, 3.0–16.4) and 20.0% in the finals (7.3 per 1,000 A-E; 95% CI, 1.0–15.5).

What is the outcome?

Injury type

Table 19.3 displays the percent distribution of injury types sustained in competition. The contusion was the most often occurring type of injury, across all studies summarized in the table.

Collapsed over sex, fractures range from 7.9% to 22.5% of all reported injuries. The foot has been found to be especially susceptible to fractures (Pieter & Zemper 1995; Koh, de Freitas & Watkinson 2001). Lacerations range from 3.7% to 25.0% when collapsed over sex.

Regardless of the definition used to classify the injury, early and recent research has highlighted the cerebral concussion as an area of concern in the epidemiology of taekwondo injuries (e.g., Pieter & Zemper 1998; Koh & Watkinson 2002a; 2002b). Table 19.4 depicts the percent distribution and competition injury rates for cerebral concussions in adults. Zemper and Pieter (1994) estimated that there was about one concussion for every 100 junior and senior competitors combined.

Time loss

Table 19.5 displays rates (with 95% confidence intervals) for overall and specific competition time-loss injuries in taekwondo as well as the estimated days lost. *Overall time-loss* injuries refer to any time-loss injury. *Specific time-loss injuries* refer to days away from taekwondo due to injury to a specific body region or body part or time away from taekwondo as a result of a specific injury type, such as a cerebral concussion.

Table 19.5 shows that the majority of competition time-loss injuries led to ≤1 week of restricted taekwondo participation. In men, the rate for

Table 19.3 Percent distribution of all reported injuries by type in *taekwondo-in*.

	Zemper & Pieter (1989)		Pieter et al. (1995)		Pieter et al. (1998)		Pieter & Zemper (1999)		Koh et al. (2001)		Beis et al. (2001)		Kazemi & Pieter (2004)	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F
Abrasion	3.7	—	—	—	—	—	1.9	2.3	4.2	—	—	33.3	2.9	—
Concussion	3.7	5	11.1	9.1	25	—	7.4	2.3	8.5	5.3	4.8	—	8.6	—
Contusion	63	75	50	90.9	50	50	48.5	53.5	28.2	50	52.4	46.7	14.3	60
Dislocation[a]	—	5	—	—	—	—	0.6	2.3	2.8	—	4.8	6.7	—	—
Epistaxis	—	—	5.6	—	—	—	1.9	5.2	—	—	4.8	6.7	2.9	—
Fracture[b]	14.8	—	11.1	—	—	—	10.5	8.1	22.5	7.9	14.3	—	—	—
Laceration	3.7	—	8.3	—	25	—	10.8	8.6	4.2	5.3	14.3	6.7	14.3	—
Sprain	3.7	5	11.1	—	—	—	11.1	8.6	14.1	23.7	4.8	—	28.6	20
Strain	3.7	5	—	—	—	—	1.5	3.5	9.9	7.9	—	—	11.4	20
Other	3.7	5	2.8	—	—	50	5.8	5.6	5.6	—	—	—	17.1	—

F = females; M = males.
[a] Includes subluxation.
[b] Includes suspected fractures.

head-and-neck time-loss injuries leading to ≤7 days of restricted activity was significantly higher than those leading to ≥21 days away from taekwondo participation: 7.6 per 1,000 A-E (95% CI, 4.7–10.6) versus 2.1 per 1,000 A-E (95% CI, 0.5–3.6) (Pieter & Zemper 1997).

Clinical outcome

Scant data are available on fatal injuries in taekwondo training or competition. Two deaths (one male adolescent and one adult) that occurred during training were described by Schmidt (1975). The technique that led to the fatal injury in the adolescent practitioner was a roundhouse kick to the celiac plexus while sparring with an advanced student. No protective equipment was worn. The cause of death was believed to be cardiac arrest as a result of vagal stimulation secondary to the kick.

The death of the adult male was a result of a spinning back kick to the left lower lateral aspect of the anterior chest while sparring with his instructor. No protective equipment was worn. The cause of death was suggested to be aspiration and asphyxia as a result of the spinning back kick (Schmidt 1975).

Table 19.4 Percent distribution and injury rates per 1,000 athlete-exposures (95% confidence interval) of cerebral concussions in adults.

Study	Males		Females	
	%	Rate	%	Rate
Zemper & Pieter (1989)	3.7	4.7 (4.5–14.0)	5.0	4.5 (4.3–13.3)
Pieter & Lufting (1994)	Not available	15.3 (4.7–25.9)	Not available	3.2 (3.1–9.6)
Pieter et al. (1995)	11.1	15.5 (0.3–30.7)	9.1	8.8 (8.42–26.0)
Pieter et al. (1998)	25.0	12.8 (12.3–38.0)	—	— (—)
Pieter & Zemper (1998)	7.4	7.0 (4.2–9.9)	2.3	2.4 (0.0–4.8)
Koh et al. (2001)	8.5	10.1 (6.0–26.2)	5.3	4.5 (2.1–11.0)
Beis et al. (2001b)	4.8	1.0 (0.9–2.9)	—	— (—)
Koh & Watkinson (2002a)	Not available	55.2 (27.2–83.1)	Not available	49.3 (12.8–85.8)
Kazemi & Pieter (2004)	8.6	6.9 (0.9–14.6)	—	— (—)

Table 19.5 Overall and specific time-loss injury rates per 1,000 athlete-exposures (95% confidence interval) in adults by sex and days lost.

Study/Body part	Men, Time Lost			Women, Time Lost		
	≤7 days	8–20 days	≥21 days	≤7 days	8–20 days	≥21 days
Pieter & Zemper (1995) (foot)	2.1 (0.5–3.6)	0.6 (0.2–1.4)	1.5 (0.2–2.8)	1.2 (0.5–2.9)	—	1.2 (0.5–2.9)
Pieter & Zemper (1997) (head & neck)	7.6 (4.7–10.6)	2.9 (1.1–4.8)	2.1 (0.5–3.6)	5.5 (1.9–9.0)	1.8 (0.2–3.9)	1.2 (0.5–2.9)
Pieter & Bercades (1997) (overall)	25.6 (9.9–61.2)	—	—	23.8 (22.9–70.5)	—	—
Pieter & Zemper (1998) (concussion)	3.2 (1.3–5.1)	0.9 (0.1–1.9)	1.2 (0.0–2.3)	1.8 (0.2–3.9)	—	—

A more recent case study reported the death of an adult female practitioner as a result of arrhythmogenic cardiomyopathy (Aguilera et al 1999). No further information was provided for this particular case.

In a prospective study, Oler et al (1991) revealed one fatal injury secondary to a spinning hook kick to the head at a national competition. The authors did not provide any demographic details, but the athlete died within 24 hours after receiving the kick. The post-mortem examination showed the following: occipital skull fracture (the hardwood floor was not matted), bilateral acute subdural hematomas, contusions of the frontal and temporal lobes, hemorrhage, and herniation of the brainstem.

What are the risk factors?

Intrinsic factors

Although skill level has been suggested to be implicated in total taekwondo competition injuries (Zandbergen n.d.), published research to establish this relationship is lacking (Pieter 1996). Zetaruk et al (2005) found that skill level (belt rank) was not a predictor of time-loss training injuries of <7 days away from practice in a group of karate, taekwondo, aikido, and kungfu athletes.

Sex Differences—Overall Time-Loss Injuries and Cerebral Concussions

Based on the data reviewed in this chapter, men were at a higher risk than women of sustaining competition time-loss injuries (relative risk, 1.5, 95% CI, 1.1–2.1; $P = 0.006$). They were also at a higher risk of incurring a cerebral concussion: relative risk, 1.9 (95% CI, 1.1–3.4, $P = 0.020$).

Table 19.4 indicates that there are differences between men and women in competition injury rates for concussions based on the point estimates, but not when the 95% confidence intervals are taken into account. The small sample sizes in each individual study may have precluded any significant differences However, when the data in Table 19.4 were combined, the men recorded an injury rate for concussions of 9.4 per 1,000 A-E (95% CI, 7.1–11.7), which is significantly higher than that for the women (4.6 per 1,000 A-E; 95% CI, 2.6–6.5). More adult males also sustained the higher grades of concussion (Pieter & Zemper 1998; Zemper & Pieter 1994).

Age differences—total injuries

Based on the data reviewed in this chapter, men are at a higher risk of incurring any injury as compared with boys: relative risk, 1.6 (95% CI, 1.4–1.8; $P<0.001$), and women are at a higher risk than girls: relative risk, 2.0 (95% CI, 1.6–2.3; $P<0.001$).

Age differences—time-loss injuries

Zetaruk et al (2005) reported that older (≥18 years) students of karate, taekwondo, aikido, and kungfu were more at risk of incurring training time-loss injuries (i.e., those that require time off from training or competition for <7 days) than their younger counterparts (odds ratio, 4.0; 95% CI, 1.5–9.5).

Based on the data reviewed in this chapter, men were at a higher risk than boys (relative risk, 1.5; 95% CI, 1.2–1.9; $P<0.001$), while women were more likely to sustain a time-loss injury in competition than girls (relative risk, 4.3; 95% CI, 3.1–5.8; $P<0.001$).

Age differences—cerebral concussions

Based on the data reviewed in this chapter, boys were more likely to sustain a cerebral concussion than men (relative risk, 1.9; 95% CI, 1.5–2.6; $P<0.001$) and girls were at higher risk than women (relative risk, 3.6; 95% CI, 2.1–6.2; $P<0.001$).

Experience—time-loss injuries

Zetaruk et al (2005) revealed that those with ⩾3 years of experience were at a greater risk of time-loss injuries of ≤7 days as compared with their less experienced colleagues (odds ratio, 2.5; 95% CI, 1.5–4.0).

Age/experience—time-loss injuries

An interaction between age and experience was found for time-loss injuries of ≥7 days away from practice or competition as well as multiple instances of time-loss injury. For those who were younger than 18 years, regardless of years of experience, the probability of time-loss injuries of ≥7 days was less than 1%. Those who were >18 years of age and had <3 years of experience had a probability of 12% to sustain a time-loss injury of ≥7 days, while those of the same age with ≥3 years of experience had a probability of 35% to sustain such time-loss injuries (Zetaruk et al 2005).

Previous injury

Koh and Cassidy (2004) reported that those who had a history of receiving a head blow leading to a concussion were at a reduced risk of getting one at the competition covered during the study period (odds ratio, 0.6; 95% CI, 0.5–0.8). This is contrary to what previous research showed (e.g., Barnes et al. 1998). It might be that those who had a history of receiving head blows were more cautious and adopted defensive techniques or evasive maneuvers and may also have improved their anticipatory skills (Koh & Watkinson 2002b).

Technique

When collapsed over age group, those who used blocking skills were less likely to receive a head blow in competition (odds ratio, 0.7; 95% CI, 0.5–0.9) or sustain a concussion (odds ratio, 0.6; 95% CI, 0.4–0.9) (Koh & Cassidy 2004).

Psychological profile

Pieter et al. (2005b) revealed a relationship between pre-competition mood and total injury. Pre-competition mood was assessed approximately 1 hour prior to competition. In women who lost and were depressed, 83.0% were correctly classified ($P = 0.004$) as injured or not injured based on anger, fatigue, and confusion—that is, those who were injured scored higher on the aforementioned mood subscales. In the men who lost and were depressed, 62.5% were correctly classified ($P = 0.035$) as injured or not injured based on fatigue; those who were injured were more fatigued.

Extrinsic factors

Although it has been suggested that rule changes that came into effect in 2002, awarding more points for head blows, might have contributed to an increase in cerebral concussions in competition (Koh & Watkinson 2002a), no analytical data are currently available to confirm this.

Zetaruk et al (2005) found that *taekwondo-in* were at higher risk than *karateka* (karate athletes) to incur time-loss injuries of <7 days (odds ratio, 3.3; 95% CI, 1.5–7.3). They were also at higher risk to sustain time-loss injuries requiring ≥7 days away from training or competition as compared with *karateka* (odds ratio, 3.7; 95% CI, 1.9–7.4).

What are the inciting events?

Table 19.6 shows the percent distribution of techniques that led to any competition injury, and Table 19.7 displays the exact circumstances that led to time-loss injuries. Beis et al. (2007) found the roundhouse and spinning hook kicks implicated in time-loss injuries (Figure 19.1).

Table 19.6 shows that when collapsed over sex, the roundhouse kick is involved in 20.0% to 66.7% of total injuries, followed by the spinning back kick with 1.5% to 36.4%. In terms of overall time-loss injuries, the roundhouse kick was the predominant technique, at 14.3% to 100.0%.

Table 19.6 Percent distribution of inciting events (frequency of techniques) involved in injury in adults.[a]

	Pieter et al (1995)		Pieter et al (1998)		Koh et al (2001)		Beis et al (2001b)	
	Men	Women	Men	Women	Men	Women	Men	Women
Roundhouse kick	66.7	63.6	25.0	50.0	56.5	65.8	47.6	20.0
Spinning hook kick	2.8	—	—	—	1.5	5.3	9.5	—
Spinning back kick	8.33	36.4	—	—	1.5	2.6	9.5	6.7
Axe kick	2.8	—	—	—	2.9	2.6	4.8	6.7
Side kick	—	—	—	—	11.6	7.9	—	—
Other	19.37	—	75.0	50.0	26.0	15.8	28.6	66.6

[a] Any circumstance for which the athlete sought treatment from the on-site medical personnel.

Table 19.7 Percent distribution of inciting event characteristics involved in time-loss injuries.[a]

	Pieter et al (1995)		Pieter & Bercades (1997)	
	M	F	M	F
Receiving roundhouse kick	42.9	—	—	—
Receiving spinning hook kick	14.3	—	—	—
Delivering roundhouse kick	14.3			100.0
Receiving spinning back kick	—	100.0	—	—
Simultaneous roundhouse kicks	—	—	50.0	—
Simultaneous punches	—	—	50.0	—
Other	28.6	—	—	—

[a] Any injury that prevented the competitor from completing the present or subsequent bout, or both, and from participating in taekwondo for a minimum of 1 day thereafter.

Figure 19.1 Spinning kicks are a common inciting event of injury. © IOC/Steve MUNDAY.

Table 19.8 presents inciting events involved in head blows in competition with and without concussion. Collapsed over gender, the axe kick was involved in most of the head blows without concussion (41.5% to 56.8%), followed by the roundhouse kick (40.0% to 51.2%). When head blows were followed by concussions, the roundhouse kick was involved in 42.9% to 75.0%.

Injury prevention

As far as is known, only Burke et al (2003) have investigated intervention measures to prevent taekwondo-related injury. The authors set out to investigate the effect of preventive measures in a heterogeneous sample of beginning to advanced practitioners ranging in age from 18 to 66 years. Punches and kicks to the face were not allowed. Comparisons were subsequently made with studies in which full-contact taekwondo injuries were investigated in homogeneous samples of mostly elite athletes. The conclusion was that the implementation of preventive measures resulted in a significantly lower injury rate.

However, the study has several methodological flaws. For example, the researchers focused on "light contact" taekwondo as opposed to the full-contact version that appears at the Olympic Games, and in the absence of injury data before the implementation of preventive measures, any reported

Table 19.8 Percent distribution of inciting events (frequency of techniques) involved in head blows or cerebral concussions.

	Koh & Watkinson (2002b)—Head Blows		Pieter et al. (1995)—cerebral Concussions		Koh & Watkinson (2002a)			
					Head Blows without Concussion		Head Blows with Concussion	
	Men	F	Men	Women	Men	Women	Men	Women
Roundhouse kick	46.7	40.0	75.0	—	51.2	40.9	53.3	42.9
Spinning back kick		5.0	—	100.0	4.9	2.3	13.3	14.3
Axe kick	46.7	55.0	—	—	41.5	56.8	26.7	28.6
Other	6.7	—	25.0	—	—	—	—	14.3

effects of these measures seem premature. Finally, the calculation of injury rates per 1,000 A-E resulted from dividing the number of total injuries by the total number of athletes, with one exposure being equal to one tournament. The investigators arrived at their injury rate per 1,000 A-E for the one time-loss injury reported by dividing the total number of participants (2,498) by 1,000 as the denominator, resulting in a time-loss injury rate of 0.4 per 1,000 A-E. Given the design issues highlighted above, the findings are considered problematic and caution is warranted in concluding that the preventive measures had any effect on reducing injuries in taekwondo.

Further research

Future research should use a uniform definition of injuries (Hodgson Phillips, 2000). In line with the current International Olympic Committee position (Junge et al. 2008), a reportable injury should be defined as "any musculoskeletal complaint newly incurred due to competition and/or training during the tournament that received medical attention regardless of the consequences with respect to absence from competition or training" (p. 414). This definition allows injuries to be recorded that include all reported injuries as well as those that lead to time loss, so that comparisons may be made with studies cited in this chapter (e.g., Pieter et al 1998; Zetaruk et al. 2000; Beis et al. 2001b).

Each taekwondo national governing body could develop its own injury surveillance system akin to the NCAA Injury Surveillance System in the United States (http://www.ncaa.org/wps/ncaa?ContentID=1126) or the Injury Information System in The Netherlands (https://bis.pgdata.nl). The latter already has an entry for martial arts. These national governing bodies could subsequently feed into an international taekwondo injury surveillance system coordinated by the WTF.

Before the effectiveness of any interventions can be evaluated, there is a need to establish baseline data. Van Mechelen et al. (1992) suggested a model on which future (longitudinal) intervention research could be based. The model may be summarized as follows: Step 1: assess the injuries; Step 2: establish the inciting events; Step 3: introduce preventive measures; and Step 4: repeat Step 1 to assess the effectiveness of Step 3.

McLatchie et al (1994) have so far conducted the only martial arts study known to this author in which, over a 10-year period, the preceding model was used by first collecting baseline karate injury data, subsequently introducing preventive measures, and finally studying the incidence of injuries again.

Preventive measures suggested in the literature that should be investigated in future research include determination of (Koh & Watkinson 2002a; 2002b; Oler et al 1991; Pieter & Lufting 1994; Pieter et al 1995; Zemper & Pieter 1989)::

- the effect of regular testing of protective equipment (since its lifespan is limited),
- the potential improvements in the headgear, especially the temporal area, and
- the effect of blocking skills, evasive maneuvers and awarding points for defensive techniques.

References

Aguilera, B., Paz Suárez Mier, M. & Morentin, B. (1999) Miocardiopatía arritmogénica como causa de muerte súbita en España: presentación de 21 casos. *Revista Española Cardiologia* **52,** 656–662.

Barnes, B.C., Cooper, L., Kirkendall, D.T., McDermott, T.P., Jordan, B.D. & Garrett, W.E. Jr. (1998) *Concussion History in Elite Male and Female Soccer Players* (Jürimäe, T. & Jürimäe, J., eds.), *American Journal of Sports Medicine* **26**, 433–438.

Beis, K., Pieter, W. & Abatzides, G. (2001a) Match characteristics and taekwondo injuries. In: Proceedings of the 7th International Scientific Conference of the International Association of Sport Kinetics. *Acta Kinesiologiae Universitatis Tartuensis* 77–80.

Beis, K., Pieter, W. & Abatzides, G. (2007) Time-loss injuries in Greek young and adult taekwondo athletes. *Journal of Sports Science and Medicine. Combat Sports Special Issue II* **6**, 45–51.

Beis, K., Tsaklis, P., Pieter, W. & Abatzides, G. (2001b) Taekwondo competition injuries in Greek young and adult athletes. *European Journal of Sport Traumatology and Related Research* **23**, 130–136.

Burke, D.T., Barfoot, K., Bryant, S., Schneider, J.C., Kim, H.J. & Levin, G. (2003) Effect of implementation of safety measures in tae kwon do competition. *British Journal of Sports Medicine* **37**(5), 401–404.

Capener, S. (1995) Problems in the identity and philosophy of t'aegwŏndo and their historical causes. *Korea Journal* **35**, 80–94.

Hodgson Phillips, L. (2000) Sports injury incidence. *British Journal of Sports Medicine* **34**, 133–136.

Junge, A., Engebretsen, L., Alonso, A.M., Renström, P., Mountjoy, M., Aubry, M. & Dvorak, J. (2008) Injury surveillance in multi-sport events: the International Olympic Committee approach. *British Journal of Sports Medicine* **42**, 413–421.

Kazemi, M. & Pieter, W. (2004) Injuries at a Canadian National Taekwondo Championships: a prospective study. *BMC Musculoskeletal Disorders* **5**, 22.

Kazemi, M., Shearer, H. & Choung, Y.S. (2005) Pre-competition habits and injuries in taekwondo athletes. *BMC Musculoskeletal Disorders* **6**, 26.

Kim, E.H., Kim, Y.S., Toun, S.W., Kim, C.J. & Chang, M.O. (1994) Survey and analysis of sports injuries and treatment patterns among Korean national athletes. *Korean Journal of Sports Science* **6**, 33–56.

Koh, J. O. & Cassidy, J.D. (2004) Incidence study of head blows and concussions in competition taekwondo, *Clinical Journal of Sport Medicine* **14**, 72–79.

Koh, J.O. & Watkinson, E.J. (2002a) Possible concussions following head blows in the 2001 Canadian National Taekwondo Championships. *Cross Boundaries—An Interdisciplinary Journal* **1**, 79–93.

Koh, J.O. & Watkinson, E.J. (2002b) Video analysis of blows to the head and face at the 1999 World Taekwondo Championships. *Journal of Sports Medicine and Physical Fitness* **42**, 348–353.

Koh, J.O., de Freitas, T. & Watkinson, E.J. (2001) Injuries at the 14th World Taekwondo Championships in 1999. *International Journal of Applied Sports Science* **13**, 33–48.

McLatchie, G.R., Commandre, F.A., Zakarian, H., Vanuxem, P., Lamendin, H., Barrault, D. & Chau, P.Q. (1994) Injuries in the martial arts. In: *Clinical Practice of Sports Injury Prevention and Care* (Renström, P.A.F.H., ed.), Volume V of the *Encyclopaedia of Sports Medicine.* Blackwell Scientific Publications, Oxford, pp. 609–623.

Moon W.J. (2003) Towards improvements in judging taekwondo competition. *International Journal of Applied Sports Sciences* **15**, 85–94.

Ohta-Fukushima M., Mutoh Y., Takasugi S., Iwata H. & Ishii, S. (2002) Characteristics of stress fractures in young athletes under 20 years. *Journal of Sports Medicine and Physical Fitness* **42**, 198–206

Oler, M., Tomson, W., Pepe, H., Yoon, D., Branoff, R. & Branch, J. (1991) Morbidity and mortality in the martial arts: a warning. *Journal of Trauma: Injury, Infection, and Critical Care* **31**, 251–253.

Pieter, W. (1995) Sportletsels, naar tak van sport: taekwondo. In: *Sportgezondheidszorg in de Praktijk* (Backx, F.J.G. & Coumans, B., eds.), Bohn Stafleu van Loghum, Houten/Zaventem 3205-1–3205-42.

Pieter, W. (1996) Martial arts. In: *Epidemiology of Sports Injuries* (Caine, D., Caine, C. & Lindner, K., eds.), Human Kinetics Books, Champaign, IL, pp. 268–283.

Pieter, W. (2005). Martial arts injuries. In: *Epidemiology of Pediatric Sports Injuries* (Caine, D., & Muffulli, N., eds.), Karger, Basel, pp. 59–73.

Pieter. W. & Bercades, L.T. (1997) Time–loss injuries in taekwondo. In: *ICHPER. SD 40th World Congress Proceedings*. Kyunghee University, Seoul, pp. 355–357.

Pieter, W. & Lufting, R. (1994) Injuries at the 1991 Taekwondo World Championships. *Journal of Sport Traumatology and Related Research* **16**, 49–57.

Pieter, W., Bercades, L.T. & Heijmans, J. (1998) Injuries in young and adult taekwondo athletes. *Kinesiology* **30**, 22–30.

Pieter, W. & Zemper, E.D. (1995) Foot injuries in taekwondo. In: *ICHPER.SD 38th World Congress Proceedings* (Varnes, J.W., Gamble, D. & Horodyski, M.B., eds.), University of Florida College of Health and Human Performance, Gainesville, FL, pp. 165–166.

Pieter. W. & Zemper, E.D. (1997) Head and neck injuries in adult taekwondo athletes. *Coach and Sport Science Journal* **2**, 7–12.

Pieter, W. & Zemper, E.D. (1998) Incidence of reported cerebral concussion in adult taekwondo athletes. *Journal of the Royal Society for the Promotion of Health* **118**, 272–279.

Pieter, W. & Zemper, E.D. (1999) Injuries in adult American taekwondo athletes. Presented at the Fifth IOC World Congress on Sport Sciences, October 31–November 5, Sydney, Australia.

Pieter. W., Van Ryssegem, G., Lufting, R. & Heijmans, J. (1995) Injury situation and injury mechanism at the 1993 European Taekwondo Cup. *Journal of Human Movement Studies* **28**, 1–24.

Pieter. W., Wong, R.S.K., Zairatulnas, W. & Thung, J.S. (2005b) Mood dimensions as predictors of injury in taekwondo. Presented at the International Society of Sport Psychology (ISSP) 11th World Congress of Sport Psychology, August 15–19, Sydney, Australia.

Schmidt, R. J. (1975) Fatal anterior chest trauma in karate trainers. *Medicine and Science in Sports* **7**, 59–61.

van Mechelen, W., Hlobil, H. & Kemper, H. C. (1992) Incidence, severity, aetiology and prevention of sports injuries: a review of concepts. *Sports Medicine* **14**, 82–99.

Zandbergen, A. (no date) *Taekwondo Blessures en Fysiotherapie*. Thesis. Twentse Akademie voor Fysiotherapie, Enschede.

Zemper, E. D. & Pieter, W. (1989) Injury rates during the 1988 US Olympic Team Trials for taekwondo. *British Journal of Sports Medicine* **23**, 161–164.

Zemper, E. D. & Pieter, W. (1994) Cerebral concussions in taekwondo. In: Hoerner, E. F. (ed.) *Head and Neck Injuries in Sports*. ASTM STM 1229. American Society for Testing and Materials, Philadelphia, PA, pp. 116–123.

Zetaruk, M. N., Zurakowski, D., Violan, M. A. & Micheli, L. J. (2000) Safety recommendations in shotokan karate. *Clinical Journal of Sport Medicine* **10**, 117–122.

Zetaruk, M. N., Violan, M. A., Zurakowski, D. & Micheli, L. J. (2005) Injuries in martial arts: a comparison of five styles. *British Journal of Sports Medicine* **39**, 29–33.

Chapter 20

Team Handball (Handball)

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Introduction

Modern handball was first played toward the end of the 19th century in Denmark, Germany, and Sweden. The first World Championship was played in Germany in 1938. Handball has been an Olympic Sport since 1972. Women's handball was introduced at the 1976 Olympic games in Montreal and has become one of the most highly attended Olympic sports (Figure 20.1). Today, handball or team handball is a sport played in 183 countries, by both sexes and in different age groups. There are 31 million players, trainers, officials, and referees worldwide acting with 1,130,000 teams (International Handball Federation 2007).

Handball is a high-intensity sport with frequent physical contact between players. The physical demands are characterized by intermittent sprinting. The match level of play includes high-speed running forward, backward, and sideways, plant and cut fakes, jumps, landings, turns, and repeated acceleration and deceleration movements. Most of the play in handball involves balancing on one or two legs while catching, bouncing (dribbling), or throwing the ball with one hand. Because of the play with hard tackling and body checking, a risk of injuries is quite obvious in handball.

The purpose of this chapter is to review the handball literature, presenting injury incidences, injury types and locations, injury mechanisms and the consequences of an injury. Finally, prevention studies will be presented, as will suggestions for future handball research.

Figure 20.1 Women's handball match from the Sydney 2000 Summer Olympics © IOC/Steve MUNDAY.

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There are some methodologic issues that make it challenging when presenting the data from the handball literature. First, the definition of a sports injury is not the same in the literature. The time-loss definition is used in most of the literature, but some investigators studying injuries in handball have included injuries that are not necessarily time-loss injuries. Jørgensen (1984) included injuries that handicapped the player, required special treatment in order to play, or both, while Wedderkopp et al. (1997, 2003) included injuries that caused the player to participate with "considerable discomfort" but did not necessarily stop the play or require medical follow-up.

Second, the definition of injury severity differs among the different studies. Van Mechelen et al. 1992, Hlobil & Kemper (1992) have described the severity of injuries based on the following criteria: nature and duration of the injury, type of treatment, sporting time lost, working time lost, permanent damage, and costs. In the literature presented in this chapter, we found different criteria used. The most-used injury classification is minor (absence of 1–7 days), moderate (8–21 days), and major (>21 days). But non-time-loss injuries are also included in some studies.

Third, the injury-registration level and methods vary between studies. In some studies, injuries are registered from hospital records or large national surveys (Fagerli et al. 1990; de Loes 1995). Recordings of injuries from hospital records or insurance companies will probably present a large number of more serious and most of these acute injuries. Minor injuries and overuse injuries will, on the other hand, be missed. Other registration methods used are questionnaires and telephone or in-person interviews. This in addition to whether the registration is done prospectively or retrospectively make the safety of the data questionable. The methodologic issues related to recall bias, overestimation or underestimation of sports participation, incomplete responses, nonresponse, drop-out, invalid injury description and problems related to the duration and cost of research are clearly of great importance when comparing the results of studies (Bahr & Holme 2003).

Who Is Affected by Injury?

Studies reporting the incidence of injury in adolescent and adult handball are shown in Tables 20.1 and 20.2, respectively. Most studies report injury rates relative to match or training. Few studies report overall injury rates in handball. This lack of information makes it difficult to compare the overall rates across competitive levels, sexes, and sports. Two studies among male players show an overall injury risk between 2.5 and 8.3 per 1,000 playing hours (Jorgensen 1984; Seil et al. 1998). The only study reporting injuries among male and female players show 0.9 and 0.5 injury per match per player (Asembo & Wekesa 1998). Among adolescents, the injury risk was low and similar among girls and boys, with 0.7 injury per 1,000 playing hours (de Loes 1995).

Wedderkopp et al. (1997) showed that back players had the highest overall incidence of injuries and the highest number of acute noncontact lower-limb injuries as compared with other player positions among young female players. This high incidence of injuries among back players was also reported by Fagerli et al. (1990).

Where Does Injury Occur?

Anatomical Location

Table 20.3 summarizes the available data on percent distribution of injuries by location in men's and women's handball. Although sample sizes are small, a picture of where injuries occur in handball is provided.

Head Injuries

Asembo and Wekesa (1998) found that 43% of the injuries among males involved the head and neck, while the numbers among females were substantially lower, at 16%. These results are similar to those reported by Langevoort et al. (2007). There seems to be few concussions among these injuries (Table 20.3), and one might expect that most of these injuries are blows to the face, nose, or possible damage to the teeth.

Upper Extremities

Acute injuries to the upper extremities are frequent and different studies report them to constitute from 7% to 50% of the total numbers of injuries

Table 20.1 Epidemiologic studies on incidence of handball injuries among adolescents.

Study	Study Design	Country and Period	Population	Injury definition	No. of Players/ Injuries	Injuries /1,000 hr		
						Match	Training	Total
Nielsen & Yde (1988)	Prospective cohort	Denmark, September 1985–May 1986	1 club, youth division Youth players Age: 7–18 yr	An incident occurring during a game and practice in the club causing the player to miss at least one game or practice session	B: 40/15 G: 54/22	B: 8.9 G: 11.4	B: 1.7 G: 2.2	
Backx et al. (1991)	Longitudinal	The Netherlands, November 1982–June 1983	Selected schoolchildren Boys and girls Age: 8–17 yr	Any physical damage caused by an accident during physical education or in any sports activities outside of school, both organized and nonorganized	B + G[a]	B + G: 14	B + G: 4.3	
de Loes (1995)	Insurance records	Switzerland, 1987–1989	Selected participants in the Swiss Organization "Youth and Sports" Age: 14–20 yr	All acute injuries occurring during the activities in "Youth and Sports"	M: 30,876/1,052 F: 10,357/371			M: 0.72 F: 0.76
Wedderkopp et al. (1997)	Retrospective cohort	Denmark, 1994–1995 (1 season)	22 teams, youth elite, intermediate, and recreational Female youth players Age: 16–18 yr	Any injury occurring during a scheduled game or practice and causing the player to either miss the next game or practice session, or being unable to participate without considerable discomfort	F: 217/211	F: 40.7	F: 3.4	
Wedderkopp et al. (1999)	RCT (of teams)	Denmark, August 1995–May 1996 (1 season)	22 teams, youth elite, intermediate and recreational Female youth players Age: 16–18 yr	Any injury occurring during a scheduled game or practice and causing the player to either miss the next game or practice session, or being unable to participate without considerable discomfort	F: 126/66	F: 23.4	F: 1.2	

Wedderkopp et al. (2003)	Retrospective cohort	Denmark, 1997–1998 (1 season)	16 teams, youth elite, intermediate and recreational Female youth players Age: 14–16 yr Female (25 teams) and male (9 teams) youth players Age: 15–18 yr	Any injury occurring during a scheduled game or practice and causing the player to either miss the next game or practice session, or being unable to participate without considerable discomfort	F: 163/[a] F: 321/48	F: 52 F: 10.4	F: 1.0
Olsen et al. (2006)[b]	Prospective cohort	Norway, September 2001–March 2002 (1 season)	34 teams (428 players) Female (25 teams) and male (9 teams) youth players Age: 15–18 yr	Any injury occurring during a scheduled match or training session, causing the player to require medical treatment or to miss at least part of the next match or training session	M: 107/13 F: 321/48	M: 8.3 F: 10.4	M. 0.6 F: 1.0
Olsen et al. (2005)	RCT	Norway, September 2002–April 2003 (1 season)	120 teams (1837 players) Female and male youth players Age: 15–17 yr	Any injury occurring during a scheduled match or training session, causing the player to require medical treatment or to miss at least part of the next match or training session	M + F: 1,837/298	IG: 4.7 CG: 10.3	IG: 0.4 CG: 0.6

B = boys; G = girls; M = males; F = females; RCT = randomized, controlled trial.
[a] Number of players and number of injuries not reported.
[b] Data from the coach report are presented.

Table 20.2 Epidemiologic studies on incidence of handball injuries among adults.

Study	Study Design	Country and Period	Population	Injury Definition	No. of Players/ Injuries	Injuries/1,000 hr		
						Match	Training	Total
Jørgensen (1984)	Retrospective cohort	Denmark, 1981–1982 40 wk	Selected players from division I–III Male players Age: 17–37 yr	Any injury occurring in connection with the game or in training that handicaps the player during the game or requires special treatment (i.e. special bandaging or medical attention) or both in order to play, or completely prevents the player from playing	M: 288/282			M: 8.3
Nielsen & Yde (1988)	Prospective cohort	Denmark, September 1985–May 1986	1 club, division I and II and lower division Male and female players Age >18 yr	An injury occurring during a game or practice causing the player to miss at least one game or practice session	M: 69/44 F: 58/24	M: 13.3 F: 13.8	M: 2.4 F: 0.7	
Seil et al. (1998)	Prospective cohort	Germany, July 1995–May 1996	16 teams, division III–IV Male players Mean age: 25.8 yr	An injury occurring during handball practice or competition leading to nonparticipation in at least one practice session or game	M: 186/91	M: 14.3	M: 0.6	M: 2.5
Asembo & Wekesa (1998)	Prospective cohort	Africa club championship April 9–17, 1995	14 teams elite 9 male teams 5 female teams Total: 406 players	Injuries leading to temporary stoppage of the game or substitution for the injured player	M: 52 injuries F: 15 injuries			M: 0.9[a] F: 0.5[a]
Petersen et al. (2002)	Prospective cohort	Germany, Aug. 2001–May 2002	1 team, division III Male players Age not reported	An injury occurring during a game or training session causing the player to miss part of the training or match, or leading to absence for at least several days of activities	M: [b]/62	M: 12.1	M: 2.6	
Langevoort et al. (2007)	Prospective cohort	EC, WC & OG Men & women	National team players Male and female	Any physical symptom incurred during a match receiving medical attention from the team physician regardless of the consequences with respect to absence from match or training	M+F: [b]/478	M: 89–129 F: 84–145 Time loss: M: 31–40[c] F: 13–36[c]		M: 1.2[a] F: 2.0[a] Time loss: M: 0.6[a] F: 0.5[a]

EC = Women's Europe Handball Championship 2002; F = females; M = males; OG = tournaments for men and women during the Olympic Games 2004; WC = Women's World Cup 2003 and Men's World Cups 2001 and 2003.

[a] Data were presented as injuries per match per player.

[b] Number of players or injuries not reported.

[c] This is injuries/1000 hours.

Table 20.3 Absolute numbers, percent comparisons, or both of injury locations among female and male handball players.

Body Part/Type of Injury	Fagerli et al. (1990)[a]		Jørgensen (1984)	Seil et al. (1998)	Asembo & Wekasa (1998)		Langevoort et al. (2007)[b]		Olsen et al. (2006), Junior Data[c]		Nielsen & Yde (1988), Senior Data		Nielsen & Yde (1988), Junior Data		Wedderkopp et al. (1997), Junior Data
	Women	Men	Men	Men	Women	Men	Men	Women	Women + Men		Women	Men	Women	Men	Women
	No. (%)	No. (%)	No. (%)	No. (%)	No. (%)	No. (%)	No. (%)	No. (%)	No. (%)	No. (%)	No. (%)	No. (%)	No. (%)	No. (%)	No. (%)
Injured body part															
Head, neck	9.6		—	4 (2)	11 (16)	29 (43)	68 (31)	8 (29)	5 (5)						
Trunk	3.5		—	2 (1)	2 (3)	13 (18)	36 (15)	2 (7)	8 (9)						
Upper extremities					2 (3)	3 (5)									
Shoulder	13		23 (8)	13 (7)			5 (2)	11 (5)	4 (4)			12 (27)	1 (5)	2 (13)	2 (1)
Arm (upper/lower)			11 (4)				3 (1)	5 (2)	2 (2)						
Elbow			18 (6)	3 (2)			7 (3)	13 (4)	4 (4)						10 (5)
Hand, including wrist, finger	36.7		17 (6)	20 (11)			18 (7)	22 (9)	16 (18)			9 (20)	5 (23)	1 (7)	2 (1)
Lower extremities	36.5				0	8 (12)									
Hip/groin			1 (2)	5 (3)			3 (2)	9 (3)	2 (2)						
Thigh			7 (16)				19 (10)	17 (6)	3 (3)		2	4 (9) (including leg)	0	2 (13) (including leg)	
Knee			25 (9)	18 (10)			27 (12)	35 (13)	24 (27)		2	3 (7)	4 (18)	1 (7)	31 (15)
Lower leg			52 (18)	9 (5)			9 (6)	17 (7)	2 (2)						
Ankle			45 (16) (foot/ankle)	14 (8)			22 (9)	28 (12)	22 (24)		9	12 (27)	10 (45)	4 (27)	56 (27)
Foot/toe			—	3 (2)			5 (2)	6 (2)	1 (1)						1 (0.5)
Others			20 (7)								1	4 (9)	2 (9)	2 (13)	0

[a] The numbers presented represents data on all age groups.
[b] The numbers for the three men and women tournaments have been merged, gives one column for female tournaments and one for male.
[c] Data from the coach report is presented.

(Jorgensen 1984; Nielsen & Yde 1988; Fagerli et al. 1990; Wedderkopp et al. 1997; Seil et al. 1998; Olsen et al. 2006; Langevoort et al. 2007). Shoulder and hand and finger injuries are most common. Finger injuries are more often observed among youth players (Table 20.3).

Lower Extremity

The majority of acute injuries in handball are located to the lower extremity, regardless of the age and gender (Nielsen & Yde 1988; Fagerli et al. 1990; Seil et al. 1998; Wedderkopp et al. 1997, 1999, 2003; Petersen et al. 2002; Reckling et al. 2003, Zantop & Petersen 2003).

The most frequent injuries reported in handball are ankle injuries (8–45%), while the most serious injuries are knee injuries (7–27%), including the anterior cruciate ligament (ACL) injury.

Environmental Location

Tables 20.1 and 20.2 present data on injury incidence in match and training among adolescent and adult handball players, respectively. In the first prospective study on handball injuries, Nielsen and Yde (1988) reported time-loss injuries among 7-to-18-year-old players in one Danish sport club. They reported an injury incidence of 10 injuries per 1,000 match-hours (11 in girls and 9 in boys). In contrast, Wedderkopp et al. (1997), based on a retrospective study in Danish handball, found that the young female players had the highest injury incidence, with up to 41 injuries per 1,000 match-hours. In their later prospective intervention study Wedderkopp et al. (1999) report that the incidence in the control group (the same players as in the previous retrospective study) was 23 injuries per 1,000 match-hours. However, since both studies include all injuries, not just time-loss injuries, the apparent difference in injury incidence may be caused by methodologic differences. Since Wedderkopp et al. (1999) did not report time-loss injuries separately, their injury incidence estimates cannot be directly compared with those of Nielsen and Yde's (1988) study (Table 20.1).

Among senior (adult) players, we see similar injury rates as among young players, with 12 to 14 injuries per 1,000 playing hours (Nielsen & Yde 1988; Seil et al. 1998; Petersen et al. 2002). The number of injuries is related to whether they report time-loss injuries or all injuries (Table 20.2). The study reporting the highest incidence of time-loss injuries is the one among national team players in international tournaments, with incidence as high as 40 injuries per 1,000 match-hours for men and 36 injuries per 1,000 match-hours for women (Langevoort et al. 2007). For the rest of the studies among senior players the injury incidence is described to be at the same level as among youth players (Table 20.2).

When looking at time-loss injuries, a sex difference is found at the national level (Langevoort et al. 2007), but minimal sex differences are described in other studies (Nielsen & Yde 1988; Olsen et al. 2006) (Table 20.2).

Match—Training

There is no doubt that the injury incidence is higher in matches than during training sessions for all injuries (Nielsen & Yde 1988; Backx et al. 1991; Seil et al. 1998; Wedderkopp et al. 1997, 1999, 2003; Petersen et al. 2002; Olsen et al. 2006) (Tables 20.1 and 20.2). The high incidence of injuries in Olympic tournaments and World Championships indicate a high injury risk in matches, especially at the top level (Langevoort et al. 2007). This picture is approximately the same for adults and adolescents, and there is no sex difference identified.

When Does Injury Occur?

Injury Onset

Injuries are often divided into acute injuries and overuse injuries. Acute injuries occur suddenly and have a clearly defined onset or cause, while overuse injuries occur gradually. The majority of injuries reported in handball, both among adolescents and adult players are acute injuries located in the lower extremity (Table 20.3).

In studies reporting both acute and overuse injuries the distribution of overuse injuries is between 7% and 21% (Nielsen & Yde 1988; Wedderkopp et al. 1997; Olsen et al. 2006). Knowledge of overuse injuries in the upper extremities is sparse, but a study among German male players showed that 40% of 25 examined players had been handicapped during training and play during the past 6 months because of shoulder pain (Gohlke et al. 1993). These results have been confirmed in a study among elite female Norwegian players (Hasslan, L., Norwegian School of Sport Sciences, Oslo, Norway, pers. comm.). Among the 178 players tested, 57% reported previous or present shoulder pain. Forty-nine (67%) of those players who had reported pain suffered from reduced training performance, and 24 (34%) could not play matches because of pain.

Seil et al. (1998) reported overuse symptoms among male nonprofessional-level players and showed that the three most dominant anatomic areas with overuse symptoms were the shoulder, lower back, and the knee.

Chronometry

Few studies report time of injury. However, Langevoort et al. (2007) reported that 45% of the injuries occurred in the middle 10 minutes of each half, and decreased toward the end. Asembo & Wekesa (1998) reported that 57% of injuries occurred in the second half. Since we do not know anything about when the players sustained an injury in relation to the exact time (minutes played), it is not possible to draw any conclusions from this information. One might suspect that players playing a full match are the ones who get most of the injuries but we do not know if this is the case.

What Is the Outcome?

Injury Type

The results of studies reporting absolute numbers, percent distribution of injuries by injury type, or both are summarized in Table 20.4. This table shows that the most common types of acute injuries in handball are muscle and ligament sprains (2–68%) (Jorgensen 1984; Nielsen & Yde 1988; Fagerli et al. 1990; Wedderkopp et al. 1997; Seil et al. 1998; Olsen et al. 2006; Langevoort et al. 2007), muscle strains (6–26%) (Jorgensen 1984; Wedderkopp et al. 1997; Seil et al. 1998; Olsen et al. 2006; Langevoort et al. 2007), and contusions (2–36%) (Jorgensen 1984; Nielsen & Yde 1988; Fagerli et al. 1990; Wedderkopp et al. 1997; Seil et al. 1998; Asembo & Wekesa 1998; Olsen et al. 2006; Langevoort et al. 2007). Fractures and dislocations are usually less common, except in the studies of Fagerli et al. (1990) and Asembo and Wekesa (1998), which showed high numbers of fractures—19% to 22% and 31%, respectively. In the study by Fagerli et al. (1990), patients were treated at an emergency department, which could explain the high numbers of fractures, while Asembo and Wekesa's (1998) study was done among elite-level male players. The latter study's high number of fractures was not found in Langevoort et al.'s (2007) data among national players, where the number of fractures was only 1% to 2%.

Few studies report overuse injuries, but in a study by Olsen et al. (2006), lower-leg pain (periostitis) was reported to be the most common problem. Some studies report injury data based on a specific diagnosis. A study of jumper's knee showed that the prevalence was 10% among female handball players and 30% among male players (Lian et al. 2005 Engebretsen & Bahr et al. 2005). Tyrdal and Bahr (1996) described elbow problems among goalkeepers and found that 41% of 729 players experienced elbow problems. The injury mechanism appeared to be repeated hyperextension trauma, and the condition was called "handball goalies elbow."

Table 20.5 presents the incidence of ACL injury in handball. In a retrospective study published in 1990, Strand et al. found that the incidence of ACL injury was highest among women playing at the top level, with 0.82 ACL injury per 1,000 playing hours, as compared with male players, with 0.31 injury per 1,000 playing hours. The relatively high incidence of ACL injuries among female players, particularly among elite players, was later confirmed by several prospective studies (Myklebust et al. 1997, 1998, 2003). The highest ACL incidence is described with elite female handball in Norway, with 2.29 ACL injuries per 1,000 match-hours (Myklebust et al. 2003). The incidence is lower among adolescents and among players in the lower divisions.

Table 20.4 Absolute numbers and/or percent comparison of injury type among female and male handball players.

Type of Injury	Fagerli et al. (1990)		Jørgensen (1984)	Seil et al. (1998)	Asembo & Wekasa (1998)		Langevoort et al. (2007)[a]		Olsen et al. (2006), Junior Data[b]		Nielsen & Yde (1988), Senior Data		Nielsen & Yde (1988), Junior Data		Wedderkopp et al. (1997), Junior Data
	Women	Men	Men	Men	Women		Women	Men	Women + Men		Women	Men	Women	Men	Women
	No. (%)	No. (%)	No. (%)	No. (%)	No. (%)		No. (%)	No. (%)	No. (%)	No. (%)	No. (%)	No. (%)	No. (%)	No. (%)	No. (%)
Concussion	1						6 (4)	6 (2)			0		0		4 (2)
Fracture	19	22		9 (10)	68 (31)		2 (1)	4 (2)			0	1 (2)	0	3 (20)	9 (4)
Dislocation	—			5 (6)		36 (15)	2 (1)	7 (3)							1 (0.5)
Tendon/ligamentous rupture, meniscus lesion	2			—	0		12 (5)	12 (6)							4 (2)
Sprain	(9)		13 (29)	42 (46)	0	5 (2)	32 (13)	42 (15)	38		14 (58)	30 (68)	15 (68)	5 (25)	129 (61)
Strain/muscle fiber rupture	—		4 (9)	24 (26)			18 (9)	16 (6)	6						25 (12)
Contusion	23	29	16 (36)	6 (7)	7 (3)	13 (4)	127 (60)	130 (54)	16		6 (25)	1 (2)	2 (9)	2 (13)	18 (9)
Laceration/abrasion/blister	2	9	0		18 (7)	22 (9)	10 (3)	9 (3)							4 (2)
Others	5	4	7 (16)				13 (5)	19 (7)	Only specified for three types		3 (13)	0	1 (5)	3 (20)	17 (8)

[a] The numbers for the three men's and women's tournaments have been merged, giving one column for women's tournaments and one for men's.
[b] Data are from the coach report.

Table 20.5 Epidemiologic studies on incidence of ACL injuries in handball.

Study Design, country and period	Study Design	Period	Population	Injury Definition	No. of players/injuries	Injuries/1,000 hr Match	 Training	 Total
Strand (1990)	Retrospective, hospital records	Norway, 1979–1989, 10 seasons	Selected players from western Norway	Total ACL ruptures occurring during handball games or play				
			division I–III Male and female		Divisions I–III Male: 111/ 7 Female: 98/18	Divisions I–III Male: 0.31 Female: 0.82		
			Division I–VII Age not reported		Divisions IV–VII Male + Female: 1,060/24	Divisions IV–VII Male + Female: 0.20		
			Youth division Age: 14–16 yr		Youth division Male + Female: 1,200/12	Youth division Male + Female: 0.08		
Myklebust et al. (1997)	Prospective cohort	Norway, 1989–1991 2 seasons	212 teams, top three divisions Male and female players Mean age for injuries: 23.8 yr (16–36) for men and 21.3 (16–34) for women	Total ACL ruptures occurring during handball games or play	Male: 1696/33 Female: 1696/54	Division I Male: 0.54 Female: 1.62 Division II Male: 0.84 Female: 1.82 Division III Male: 0.27 Female: 0.72		
Myklebust et al. (1998)	Prospective cohort	Norway, 1993–1996 3 seasons	24 teams, elite division male and female players Mean age for injuries 23.4 yr for men and 21.9 for women	Total ACL ruptures occurring during organized handball training or games	Male: 144/5 Female: 144/23	Male: 0.23 Female: 1.60	Men: 0.03 Women: 0.03	Men: 0.06 Women: 0.31
Myklebust et al. (2003)	Prospective cohort	Norway, August 15 1998– May 31 1999, 10.5 mo	60 teams, top three division Female players Mean age for injuries 22 yr	Total ACL ruptures occurring during organized handball training or games	All divisions: 942/29 Elite: 225/13	All divisions: 1.48 Elite: 2.79	All divisions: 0.03 Elite: 0.03	All divisions: 0.14 Elite: 0.19

ACL = anterior cruciate ligament; M = Male; F = Female

Some handball studies have reported a possible association between age and ACL injuries. Strand et al. (1990) reported that 35% and 25% of ACL injuries occurred in the 15-to-19- and 20-to-24-year age groups, respectively. Reckling et al. (2003) reported that of 12 ACL tears recorded in 100 adolescent and youth handball players (ages 8–18), 11 were in the age group 15 to 18, 1 was in 12 to 14, and none were in 8 to 12). However, these studies were retrospective and they have no comparable data on noninjured players. The high number of injured players may, rather, reflect the high number of participants in these age groups, so prospective studies are needed before age can be identified as a potential risk factor for ACL injury among handball players (Olsen 2005a).

Time Loss

Some studies have reported details regarding time-loss injuries. Twenty percent of the players in one study (Nielsen & Yde (1988) reported absence from handball because of injury for >4 weeks. In a study reported by Langevoort et al. (2007), 23% of the injuries prevented the player from participating in a match or training for ≤1 week and 5% of the injuries led to longer absences. Ankle, knee, and head injuries most frequently led to absences. In addition, Langevoort et al. (2007) found that significantly more noncontact than contact injuries were expected to result in absence from handball.

In a study of youth players Olsen et al. (2006) reported that 56% of the acute match injuries and 50% of acute training injuries were moderate (≤8 days lost) or major (≥21 days lost) injuries. Notably, 64% of the overuse injuries in this study were either moderate or major injuries.

Clinical Outcome

Studies have shown that 5% to 36% of the injuries are major (absence from team activities >3 or 4 weeks), and that reinjuries are common (Nielsen & Yde 1988; Seil et al. 1998; Wedderkopp et al. 1999, 2003; Myklebust et al. 2002; Olsen et al. 2006; Langevoort et al. 2007). More serious injuries could affect the athlete's physical fitness and the team's performance. In addition, it could influence other aspects, such as time lost from school and work. Nielsen and Yde (1988) found that 41% of the players who incurred injuries during the study period still had symptoms 6 months after the end of the season. One might assume that many minor or moderate injuries are not followed by a complete rehabilitation, which could be a risk factor for new injury or reinjury. A study among handball players showed that the risk of a reinjury of a reconstructed ACL was 13% after returning to match play (Myklebust et al. 2002).

Osteoarthritis (OA) is a possible consequence after an ACL injury, whether the patient has had surgery or has been treated conservatively. Persons with knee OA suffer from swelling and pain, loss of range of motion, and often altered function with diminished muscle strength (Gillquist & Messner 1999). Myklebust et al. (2002) showed that the prevalence of OA was 42% among surgically treated patients and 46% among nonsurgically treated patient 6 to 11 years after ACL injury. These high numbers were confirmed in the study conducted by von Porat et al. (2004) among soccer players. L'Hermette et al. (2006) found that 60% of retired male handball players were diagnosed with premature hip OA, as compared with 13% of the control subjects.

Economic Cost

Some studies have evaluated the costs of severe knee injuries; predominantly ACL injuries. The cost of this injury is not easy to estimate. A sum of US$17,000 per injury has been estimated when including only surgical and rehabilitation costs. Engebretsen (Ullevål University Hospital and Faculty of Medicine University of Oslo, pers. comm.) estimated the total costs to be approximately 500,000 NOK (US$91,000) over the athlete's life span when including long-term disability, sick leave, and the possibility of additional surgical procedures.

Forssblad et al. 2005, Weidenhielm, and Werner (2005) looked at health care costs for knee surgery directly related to participation in different sports in Sweden. They found that the overall cost per player was estimated to be SEK 108 (US$18). They conclude that sports participation can lead to injuries, but in relation to the costs of an inactive lifestyle, the costs of sports injuries are low.

In one study looking at socioeconomic costs of sports injuries in Flanders, Cumps et al. (2008) found that the highest direct medical costs were found for ACL injuries (US$1889 per injury) and the lowest for foot injuries (US$72 per injury).

What Are the Risk Factors?

The combination of intrinsic and extrinsic factors, and the interaction between them, could make the athlete vulnerable to injury (Bahr & Maehlum 2004). For a successful rehabilitation and to make effective prevention programs, it is important to know the athletes' relevant risk factors.

Intrinsic Factors

Sex

Studies of team handball players have shown that women have an incidence of ACL injuries 3 to 5 times higher than that of men (Ferretti et al. 1992; Lindenfeld et al. 1994; Arendt & Dick 1995; Hutchinson & Ireland 1995; Bjordal et al. 1997; Myklebust et al. 1997, 1998; Powell & Barber-Foss 2000).

Previous Injury

Although two studies of handball players have shown that 30% to 35% of injuries were injuries of the same type and location as those that occurred in the previous season (Nielsen & Yde 1988; Wedderkopp et al. 1997), and one study showed a propensity for players to reinjure their ACLs (Drogset & Grontvedt 2002), only one study actually tested this relation. Myklebust et al. (2002) found that 13% of players who continued to play handball after their ACL reconstruction reruptured their ACL, but there was no difference between this group and players who ruptured their previously uninjured ACL, which indicates that previous ACL injury is not a risk factor for having a new ACL injury to the same knee (Myklebust et al. 2002).

Extrinsic Factors

Level of Play

Several studies have analyzed the relation between level of play and injury; however, the findings for lower-limb injuries in general are contradictory (Murphy et al. 2003). The picture is more apparent when studying ACL injuries. Strand et al. (1990) reported that female players in the three top divisions have a higher incidence of ACL injury than players playing at lower levels. This has been confirmed by Myklebust et al. (1998, 2003), who found the highest incidence of ACL injuries among female elite players. The same pattern is found among soccer players (Roos et al. 1995; Bjordal et al. 1997).

Competition versus Practice

There is no doubt that injury incidence is higher in matches than during training sessions for all injuries (see Tables 20.1 and 20.2). The overall incidence in handball has been found to be 4 and 24 times higher in matches (Nielsen & Yde 1988; Backx et al. 1991; Wedderkopp et al. 1997, 1999, 2003; Seil et al. 1998; Petersen et al. 2002). It appears to be approximately the same for adolescents and adults, and no sex difference has been identified. Regarding ACL injuries there is an 8 times higher match incidence among men and a 53 to 93 times higher match incidence among women (Myklebust et al. 1998, 2003).

Player Position

As presented in the section on "Who Is Affected by Injury,", several studies (Jorgensen 1984; Fagerli et al. 1990; Wedderkopp et al. 1997) have shown a higher incidence of injuries among back players. Several studies have shown that the relative risk of ACL injury is also higher among back players (Myklebust et al. 1997, 1998, 2003). Another trend is that the proportion of back players injured is even higher when studying the elite level only (Myklebust et al. 1998). One reason for this could be that the back players perform most of the plant and cut movements and the jump shots; in addition, they have more ball contact than players at other positions.

Shoe–Floor Interaction

Shoe–surface interaction has been studied as an ACL injury risk factor in different sports. In handball, it has been shown that the risk of ACL injury is 2.4

times greater when competing on artificial floors (with an increased coefficient of friction) as compared with wooden floors (Olsen et al. 2003). There is little doubt that the shoe–playing surface interface is important to consider when developing intervention strategies to reduce the incidence rate of serious knee injuries.

What Are the Inciting Events?

Most injuries in handball occur in a contact situation. Studies report contact injuries to be between 40% and 84% (Nielsen & Yde 1988; Fagerli et al. 1990; Langevoort et al. 2007). Some studies have reported information regarding the mechanism of an ACL injury. In approximately 90% of the cases, the injury is a noncontact injury in the attacking phase of the play while the players are doing a plant and cut or a landing after a jump shot (Myklebust et al. 1997, 1998, 2003).

Injury Prevention

Prevention is the ultimate goal of sports injury epidemiology (Bahr et al. 2002, Kannus & van Mechelen 2002), and as soon as there is evidence that points to an association between certain risk factors and injury it is natural to test this through an intervention (Caine et al. 1996). The number of preventive studies in sports is not impressive. Nevertheless, handball is one of the sports in which injury-prevention interventions have been performed, and these studies are presented in Table 20.6. As shown, there have been six studies, including one case–control study, two prospective cohort studies, and three randomized, controlled trials.

In 1999, Wedderkopp et al. showed that a 10–15 min program with balance-board training and a special warm-up and training program for all muscle groups yielded a significant reduction of both overuse and acute injuries among youth female players. This is the only study that has shown a reduction of overuse injuries. In the other studies presented in Table 20.6 the goal has been to reduce acute ankle and knee injuries.

In a randomized, controlled trial among youth female and male players, Olsen et al. (2005) showed that a structured warm-up program significantly reduced acute lower-extremity injuries among players in the intervention group. In this study, the teams were highly compliant with the program—87% of the teams performed the program as intended. In addition, the sample size was high enough to detect a difference between the intervention and control groups. In some of the studies presented in Table 20.6, the number of teams or players is too low to detect a difference between the groups.

In the prospective cohort study by Myklebust et al. (2003), a five-phase neuromuscular training program was tried out among female players. The intervention significantly reduced ACL injuries from the control season to the second intervention season among the elite players who completed the program, and they also found a significant reduction in the risk of noncontact ACL injuries. A video presentation of the prevention programs of Olsen et al. and Myklebust et al. studies is found at www.ostrc.no and www.skadefri.no.

Despite the relatively sparse number of studies, we can conclude that it is possible to prevent acute ankle and knee injuries in handball. Studies from comparable sports, such as soccer (Mandelbaum et al. 2005) and basketball (Hewett et al. 1999) have confirmed that it is possible to prevent this injury. For more details on ACL injury prevention, the reader is referred to the results of an ACL consensus meeting (Griffin et al. 2006).

Further Research

The review of the handball injury literature has clearly shown that there are gaps and weaknesses in the epidemiology literature.

- First, there is a need for an injury surveillance system to obtain information of all kind of injuries, both overuse and acute injuries. It should be carried out throughout the whole season, including the preseason. This knowledge will help to target an age group or an injury type if the incidence of injury changes. This will also help us to know where the preventing efforts must be focused and to see whether there is a need for a change to the rules of the play. In addition, it will make it possible to point out possible seasonal changes

Table 20.6 Injury-prevention studies in handball.

Study	Study Design	Type of Intervention	Level and Country	Study Group	Injury Definition and Registration	Comparison of Interventions	Follow-up	Results (RR or OR provided if adequate information provided)
Wedderkopp et al. (1999)	RCT (of teams)	Warm-up, balance board, strength, play, cool-down, stretching, primary	Youth elite, intermediate recreational Denmark	237 female players 11 teams in each group (IG = 111 players; CG = 126 players) Age: 16–18 yr	Acute and overuse; Time loss or participate with "considerable discomfort" Coach; injury form (every 10 days)	IG: 10–15 min balance-board training and a special warm-up and training program for all major muscle groups (upper and lower limbs) at all practice sessions CG: Train and play as usual	10 mo (August–May)	Significant reduction of both overuse and acute injuries in IG, including ankle sprains RR, 0.17; 95% CI, 0.09–0.32
Petersen et al. (2002)	Prospective cohort	Balance board, jump training, primary	Divisions II–III Germany	Male players[a] 1 division II (18 players) in the IG 1 Division III team[a] in the CG Age not reported	Acute; Time loss or interruption Team PT; injury form (frequency not reported)	IG: A program including information on injury mechanisms, and proprioceptive and jump training at every practice session (10 min) in the 8 wk preseason, then proprioceptive training 1–2 times (5 min) per week during season) CG: Train and play as usual	10 mo (August–May)	Lower number of knee and ankle injuries in IG (*P* = NS)
Myklebust et al. 2003	Prospective cohort	Neuromuscular training (balance, polymetric)	Divisions I–III Norway	2,647 female players 60 teams (942 players) in CS 58 teams (855 in first IS 52 teams (850 players) in second IS Mean age at injury 22 yr	ACL Coach and/or team PT; injury form (telephone every 1–2 mo	CS: Baseline data on the incidence and mechanism. Train and play as usual Introduction of an ACL injury prevention program: 15 min balance exercises (floor, mat and board) 3 times weekly during 5–7 week in the preparatory period, and then 1 times per week during the season Second IS (intervention section): Modifying the ACL prevention program to make it more challenging and specific to handball	3 seasons (10.5 mo each season; August 15–May 31)	A significant reduction in the incidence of ACL injuries from CS to second IS among elite players who completed the intervention program OR, 0.06; 95% CI, 0.01–0.54

(*continued*)

Table 20.6 (*continued*)

Study	Study Design	Type of Intervention	Level and Country	Study Group	Injury Definition and Registration	Comparison of Interventions	Follow-up	Results (RR or OR provided if adequate information provided)
Wedderkopp et al. 2003	RCT (of teams)	Warm-up, balance board, strength, play, cool-down. Stretching primary, rehabilitation, secondary	Youth elite, intermediate recreational Denmark	163 female players 8 teams in each group (AD = 77 players; NAD = 86 players) Ages 14–16 yr	Acute and overuse; Time loss or participate with "considerable discomfort"	AD: Functional strength and 10–15 min balance-board training at all practice sessions NAD: Functional strength only (non–balance board) at all practice sessions	9 mo (August–April)	Significantly fewer acute injuries in the AD group. No reduction of lower-limb injuries in AD OR, 0.21; 95% CI, 0.09–0.53 Multivariate analysis, but no control of cluster randomization in analysis
Petersen et al 2005	Prospective case–control study	Information about injury mechanism Balance board, jump training	Senior female players Two teams semiprofessional, four teams superior amateur level, four teams lower amateur level Germany	IG: 134 female players (10 teams) CG: 142 players (10 teams)	Acute: Time loss Weekly contact with each team	IG: An 8-week preseason program; proprioceptive and jump training three times a week (10 min), then once a week during the season CG: Train and play as usual	One season	IG: reduced risk of ankle or ACL injury compared to CG (P = NS) Ankle: OR, 0.55; 95% CI, 0.22–1.43 ACL: OR, 0.17, 95% CI, 0.02–1.5
Olsen et al. 2005	RCT cluster randomized	Structured warm-up program	Youth players Norway	120 teams 1837 male and female players IG = 958 players; (808 women and 150 men) CG = 879 players (778 women and 101 men) Ages: 15–17 yr	Time-loss injuries. PT blinded regarding IG or CG; called teams every month	IG: Introduction of a structured warm-up program to improve running, cutting, and landing techniques as well as neuromuscular control, balance, and strength CG: Train and play as usual	8 mo (September–April)	The number of ankle and knee injuries was significantly reduced in the IG (50% reduction of acute ankle and knee injuries, even higher reduction among severe injuries) Intervention versus control group: RR, 0.53; 95% CI, 0.35–0.81

AD = ankle disk group; CG = control group; CS = control season; IG = intervention group; IS = intervention season; NAD = non–ankle disk group; NS = not significant; PT = physical therapist; RCT = randomized, controlled trial; RR = rate ratio.

[a] Number of players not reported.

in injury risk—for example, injuries related to the preseason—before the match season starts.

- Agreement and clarification of injury definition is necessary to be able to compare studies within the sport of handball as well as with other sports.
- There is a special need for research regarding overuse injuries. Coaches report that overuse injuries are a problem for the continuity of the training. More precise information about shoulder and back injuries is needed. These are mostly overuse injuries, for which injury mechanisms are more difficult to investigate.
- An effort should be made to gain consistent knowledge on injury mechanisms. These are necessary to understand before introducing the best and most effective prevention measures.
- There is a need for risk-factor studies to help us to make the prevention strategies more specific.
- A closer look at the increased risk of head injuries, injury type, and injury mechanisms is necessary. A video study of matches could point out risk factors.
- Exploration of the risk of reinjury in relation to rehabilitation of the first injury is necessary.
- There is a need to study long term-consequences of severe injuries, such as ACL injuries, in relation to quality of life and personal and social economic costs.
- The shoe–floor friction interaction should be explored more closely.
- Taping and bracing should be performed to avoid new injuries while an injury is being rehabilitated.
- For young athletes playing at a high level, it is necessary to test the effectiveness of a rule limiting the number of matches or competitions that can be played per unit time.
- The use of protective equipment in handball needs to be standardized. Research is also needed to determine the effectiveness of padded knee and elbow protection to avoid injury.

References

Arendt, E. & Dick, R. (1995) Knee injury patterns among men and women in collegiate basketball and soccer. NCAA data and review of literature. *American Journal of Sports Medicine* **23**, 694–701.

Asembo, J.M. & Wekesa, M. (1998) Injury pattern during team handball competition in east Africa. *East African Medical Journal* **75**, 113–116.

Backx, F.J., Beijer, H.J., Bol, E. & Erich, W.B. (1991) Injuries in high-risk persons and high-risk sports: a longitudinal study of 1818 school children. *American journal of Sports Medicine* **19**, 124–130.

Bahr, R. & Holme, I. (2003) Risk factors for sports injuries—a methodological approach. *British Journal of Sports Medicine* **37**, 384–392.

Bahr, R., Kannus, P., & van Mechelen, W. (2003) Epidemiology and prevention of sports injuries. In: *Textbook of Sports Medicine* Edited by Michael Kjær, Michael Krogsgaard, Peter Magnusson, Lars Engebretsen, Harald Roos, Timo Takala and Savio L-Y Woo. Blackwell Science Ltd. Massachusetts, USA

Bahr, R. & Maehlum, S. (2004) *Clinical Guide to Sports Injuries.* Human Kinetics, Champaign, IL.

Bjordal, J. M., Arnly, F., Hannestad, B., & Strand, T. (1997) Epidemiology of anterior cruciate ligament injuries in soccer. *American Journal of Sports Medicine* **25**, 341–345.

Caine, D. J., Caine, C. G., & Lindner, K. J. (eds) (1996) *Epidemiology of Sports Injuries*. Human Kinetics, Champaign, IL.

Cumps, E. D., Verhagen, E., Annemans, L., & Meeusen, R. (2008) Injury rate and socio-economic costs resulting from sports injuries in Flanders. Data derived from Sports Insurance Statistics 2003. *British Journal of Sports Medicine* **42,** 767–772.

de Loes M. (1995) Epidemiology of sports injuries in the Swiss organization "Youth and Sports" 1987–1989: injuries, exposure and risks of main diagnoses. *International Journal of Sports Medicine* **16**, 134–138.

Drogset, J. O. & Grontvedt, T. (2002) Anterior cruciate ligament reconstruction with and without a ligament augmentation device : results at 8-year follow-up. *American Journal of Sports Medicine* **30**, 851–856.

Fagerli, U.M., Lereim, I., & Sahlin, Y. (1990) [Injuries in handball players]. *Tidsskrift for den Norske Laegeforening* **110**, 475–478.

Ferretti, A., Papandrea, P., Conteduca, F., & Mariani, P.P. (1992) Knee ligament injuries in volleyball players. *American Journal of Sports Medicine* **20**, 203–207.

Forssblad, M., Weidenhielm, L., & Werner, S. (2005) Knee surgery costs in football, floor ball, European team handball and ice hockey. *Scandinavian Journal of Science and Medicine in Sports* **15**, 43–47.

Gillquist, J. & Messner, K. (1999) Anterior cruciate ligament reconstruction and the long-term incidence of gonarthrosis. *Sports Medicine* **27(3)**, 143–156.

Gohlke, F., Lippert, M.J., & Keck, O. (1993) [Instability and impingement of the shoulder of the high performance athlete in overhead stress]. *Sportverletzung Sportschaden* **7**, 115–121.

Griffin, L.Y., Albohm, M.J., Arendt, E.A., Bahr, R., Beynnon, B.D., Demaio, M., Dick, R.W., Engebretsen, L., Garrett, W.E., Jr., Hannafin, J.A., Hewett, T.E., Huston, L.J., Ireland, M.L., Johnson, R.J., Lephart, S., Mandelbaum, B.R., Mann, B.J., Marks, P.H., Marshall, S. W., Myklebust, G., Noyes, F.R., Powers, C., Shields, C., Jr., Shultz, S.J., Silvers, H., Slauterbeck, J., Taylor, D.C., Teitz, C.C., Wojtys, E.M. & Yu, B. (2006) Understanding and preventing noncontact anterior cruciate ligament injuries: a review of the Hunt Valley II meeting, January 2005. *American Journal of Sports Medicine* **34**, 1512–1532.

Hewett, T.E., Lindenfeld, T.N., Riccobene, J.V. & Noyes, F.R. (1999) The effect of neuromuscular training on the incidence of knee injury in female athletes: a prospective study. *American Journal of Sports Medicine* **27**, 699–706.

Hutchinson, M.R. & Ireland, M.L. (1995) Knee injuries in female athletes. *Sports Medicine* **19**, 288–302.

International Handball Federation. www.ihf.info 1997

Jorgensen, U. (1984) Epidemiology of injuries in typical Scandinavian team sports. *British Journal of Sports Medicine* **18,** 59–63.

Langevoort, G., Myklebust, G., Dvorak, J., & Junge, A. (2007) Handball injuries during major international tournaments. *Scandinavian Journal of Science and Medicine in Sports* **17 (4)**, 400–407.

L'Hermette, M., Polle, G., Tourny-Chollet, C. & Dujardin, F. (2006) Hip passive range of motion and frequency of radiographic hip osteoarthritis in former elite handball players. *British Journal of Sports Medicine* **40 (1)**, 45–49.

Lian, O. B., Engebretsen, L. & Bahr, R. (2005) Prevalence of jumper's knee among elite athletes from different sports: a cross-sectional study. *American Journal of Sports Medicine* **33 (4)**, 561–567.

Lindenfeld, T.N., Schmitt, D.J., Hendy, M.P., Mangine, R.E. & Noyes, F.R. (1994) Incidence of injury in indoor soccer. *American Journal of Sports Medicine* **22 (3)**, 364–371.

Mandelbaum, B.R., Silvers, H.J., Watanabe, D.S., Knarr, J.F., Thomas, S.D., Griffin, L.Y., Kirkendall, D.T. & Garrett, W., Jr. (2005) Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: 2-year follow-up. *American Journal of Sports Medicine* **33**, 1003–1010.

Murphy, D.F., Connolly, D.A., & Beynnon, B.D. (2003) Risk factors for lower extremity injury: a review of the literature. *British Journal of Sports Medicine* **37**, 13–29.

Myklebust, G., Bahr, R., Engebretsen, L., Holm, I. & Maehlum, S. (2002) Clinical, functional and radiological outcome 6-11 years after ACL injuries in team handball players - a follow-up study. *The American journal of sports medicine*.

Myklebust, G., Engebretsen, L., Braekken, I.H., Skjolberg, A., Olsen, O.E. & Bahr, R. (2003) Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons. *Clinical Journal of Sport Medicine: Official Journal of the Canadian Academy of Sport Medicine* **13**, 71–78.

Myklebust, G., Maehlum, S., Engebretsen, L., Strand, T. & Solheim, E. (1997) Registration of cruciate ligament injuries in Norwegian top level team handball: a prospective study covering two seasons. *Scandinavian Journal of Science and Medicine in Sports* **7**, 289–292.

Myklebust, G., Maehlum, S., Holm, I. & Bahr, R. (1998) A prospective cohort study of anterior cruciate ligament injuries in elite Norwegian team handball. *Scandinavian Journal of Science and Medicine in Sports* **8**,149–153.

Nielsen, A.B. & Yde, J. (1988) An epidemiologic and traumatologic study of injuries in handball. *International Journal of Sports Medicine* **9**, 341–344.

Olsen, O.E., Myklebust, G., Engebretsen, L. & Bahr, R. (2006) Injury pattern in youth team handball: a comparison of two prospective registration methods. *Scandinavian Journal of Science and Medicine in Sports* **16 (6)**, 426–432.

Olsen, O.E., Myklebust, G., Engebretsen, L., Holme, I. & Bahr, R. (2003) Relationship between floor type and risk of ACL injury in team handball. *Scandinavian Journal of Science and Medicine in Sports* **13,** 299–304.

Olsen, O.E., Myklebust, G., Engebretsen, L., Holme, I., & Bahr, R. (2005) Exercises to prevent lower limb injuries in youth sports: cluster randomised controlled trial. *British Medical Journal* **330**, 449.

Petersen, W., Zantop, T., Steensen, M., Hypa, A., Wessolowski, T. & Hassenpflug, J. (2002) [Prevention of lower extremity injuries in handball: initial results of the handball injuries prevention programme]. *Sportverletzung Sportschaden* **16**, 122–126.

Powell, J.W. & Barber-Foss, K.D. (2000) Sex-related injury patterns among selected high school sports. *American Journal of Sports Medicine* **28**, 385–391.

Reckling, C., Zantop, T. & Petersen, W. (2003) [Epidemiology of injuries in juvenile handball players]. *Sportverletzung Sportschaden* **17,** 112–117.

Roos, H., Ornell, M., Gardsell, P., Lohmander, L.S., & Lindstrand, A. (1995) Soccer after anterior cruciate ligament injury—an incompatible combination? A national survey of incidence and risk factors and a 7-year follow-up of 310 players. *Acta Orthopaedica Scandinavica* **66**, 107–112.

Seil, R., Rupp, S., Tempelhof, S. & Kohn, D. (1998) Sports injuries in team handball: a one-year prospective study of sixteen men's senior teams of a superior nonprofessional level. *American Journal of Sports Medicine* **26**, 681–687.

Strand, T., Tvedte, R., Engebretsen, L. & Tegnander, A. (1990) [Anterior cruciate ligament injuries in handball playing: mechanisms and incidence of injuries]. *Tidsskrift for Den Norske Lægeforening* **110**, 2222–2225.

Tyrdal, S. & Bahr, R. (1996) High prevalence of elbow problems among goalkeepers in European team handball—"handball goalie's elbow." *Scandinavian Journal of Science and Medicine in Sports* **6**, 297–302.

van Mechelen, W., Hlobil, H. & Kemper, H.C. (1992) Incidence, severity, aetiology and prevention of sports injuries: a review of concepts. *Sports Medicine* **14**, 82–99.

von Porat, A., Roos, E.M. & Roos, H. (2004) High prevalence of osteoarthritis 14 years after an anterior cruciate ligament tear in male soccer players: a study of radiographic and patient relevant outcomes. *British Journal of Sports Medicine* **38**, 263.

Wedderkopp, N., Kaltoft, M., Holm, R. & Froberg, K. (2003) Comparison of two intervention programmes in young female players in European handball—with and without ankle disc. *Scandinavian Journal of Science and Medicine in Sports* **13**, 371–375.

Wedderkopp, N., Kaltoft, M., Lundgaard, B., Rosendahl, M. & Froberg, K. (1997) Injuries in young female players in European team handball. *Scandinavian Journal of Science and Medicine in Sports* **7**, 342–347.

Wedderkopp, N., Kaltoft, M., Lundgaard, B., Rosendahl, M. & Froberg, K. (1999) Prevention of injuries in young female players in European team handball: a prospective intervention study. *Scandinavian Journal of Science and Medicine in Sports* **9**, 41–47.

Chapter 21

Tennis

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Introduction

The modern game of tennis ("lawn tennis") originated in Europe in the late 19th century, with its roots going back to the ancient game of real tennis. Tennis spread first throughout the English-speaking world (Great Britain and the United States), particularly among the upper classes. Today, tennis is played by millions of people, and more than 200 countries are affiliated with the International Tennis Federation. Tennis is also a very popular spectator sport, especially the four Grand Slam tournaments: Australian Open, French Open, Wimbledon, and the U.S. Open.

Tennis was part of the Summer Olympic Games program from the very beginning, in 1896. At the 1896 Summer Olympics two tennis events were played, both for men. Tennis was dropped from the Olympic program after 1924 as a result of discussions over amateurism and professionalism. However, tennis returned as a demonstration sport to the 1984 Summer Olympics in Los Angeles. At the next Games in 1988, tennis was once again an official sport and has continued as a part of the Games since then. Olympic medals can be won in men's and women's singles and doubles.

But tennis is more than a sport to watch and a sport to enjoy. Playing tennis is also associated with significant health benefits. A positive association has been shown between regular tennis participation and positive health benefits, including improved aerobic fitness, a leaner body, a more favorable lipid profile, improved bone health and a reduced risk of cardiovascular morbidity and mortality (Pluim et al. 2007).

Injury has been identified as an important reason why participants drop out of tennis (Otis et al. 2006). Like many other sports, playing tennis—at either a recreational, college, or professional level—places participants at risk of injury. Tennis injuries are a common cause of disability and, in some cases, absence from work. This can have substantial socioeconomic consequences, both on a personal and a societal level, and reduces the chances for someone to enjoy tennis as a lifetime sport.

For these reasons, it is important to develop effective measures for the prevention of tennis injuries. The aim of this chapter is to provide an overview of the available scientific knowledge on the occurrence, causes, risk factors, and prevention of tennis injuries.

Methodologic Limitations

In order to identify risk factors in tennis, the preferred study design is a prospective longitudinal cohort study of players at risk for injury, controlled for possible confounders. However, the majority of the retrieved studies had a cross-sectional design, excluding the possibility of establishing a causal relationship. Furthermore, most studies did not adequately correct for confounding factors. Very

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few cohort studies were identified that estimated a measure of association between risk factors and the occurrence of tennis injuries, and no randomized, controlled trials on preventive measures in tennis were identified.

Who Is Affected by Injury?

The studies reporting incidence rates are summarized in Table 21.1. A review of this table shows that incidence rates in tennis vary from 0.0003 to 2.9 injuries per player per year, and from 0.11 injury to 5.0 injuries per 1,000 hours of play. The variation in the reported incidence rates of tennis injuries reflects variation in injury definition, study design, populations under study, methods of data collection, and duration of follow-up or recall period.

The lowest injury rates (0.3 injury per 1,000 players per year and 0.5 injury per 1,000 hours of play) were reported in the Victorian Injury Surveillance System (VISS) (Routley & Valuri 1993) and the Letsel Informatie Systeem (Oldenziel & Stam 2008; Stam 2004; Schoots et al 1999, Ten Hag & Toet 1999) studies, respectively. Injuries in these studies included only those for which the player was treated at a hospital emergency department. This implies that predominantly more acute and serious injuries would be reported, as players with less serious and chronic injuries were more likely to visit their general practitioner, physiotherapist, or sports physician or to self-treat.

The other study with a relatively low injury rate (0.11 injury per 1,000 hours of play) was by Weijermans et al. (1998). In that study, injuries sustained by tennis players at a club had to be reported to a contact person in order to be recorded. This may have resulted in underreporting of injuries. Biener and Caluori (1976a, 1976b, 1976c) also reported a relatively low injury rate—0.05 injury per player per year—which can be explained by their long recall period of 17.5 years.

The highest injury rates, ranging from 6.9 medical treatments per 1,000 games played to 37 injures per 1,000 athlete-exposures (AEs), were reported in three studies (Hutchinson et al. 1995; Safran et al. 1999; Silva et al. 2003), This is undoubtedly related to their rather inclusive injury definitions: "any medical problem that required physical or medical assistance" (Hutchinson et al. 1995; Safran et al. 1999) and "any consultation and/or treatment given to a player during a tournament on site" (Silva et al. 2003). Using these definitions, injuries that may not have had any effect on tennis play, time loss, or work were also included. Kühne et al. (2004) addressed this problem by making a separate category for "Bagatellverletzungen" (minor injuries), which included sunburns, abrasions, and blisters.

Where Does Injury Occur?

Anatomical Location

Identification of the most commonly injured anatomical sites in tennis is an important indication of areas that should be targeted for preventive measures. A percentage comparison of injury location of reported studies in tennis players is shown in Table 21.2. A review of these studies shows that the lower extremity is the most frequently injured region in tennis players (range, 39–65%), followed by the upper extremity (range, 24–46%) and the head/trunk (range, 8–22%). The retrospective data show a fairly similar distribution over the lower extremity (range, 31–61%), upper extremity (range, 22–48%), and head/trunk (range, 8–20%).

The most frequently injured parts of the lower body were the lower leg, ankle, and thigh, with the ankle sprain and thigh muscle strain as most frequent injuries. Upper-extremity injuries were most frequently located in the elbow and shoulder, with tendon injuries of the shoulder and tennis elbow (lateral epicondylitis) as the most frequent injuries.

When Does Injury Occur?

Injury Onset

With the exception of one study (Jayanthi et al. 2005), all of the studies reporting injury onset report that the majority of injuries were of a sudden nature, ranging from 55% to 75% of all injuries sustained (Reece, 1986; Baxter-Jones et al. 1993, Maffulli & Helms 1993; Weijermans et al. 1998; Kühne et al.

Table 21.1 A comparison of injyury rates in tennis.

Study[a]	Country	Study Design	Data Collection	Duration of Injury Surveillance	No. of Injuries	Study Population	Injury Definition	No. of Injuries/ 1,000 hr of Exposure	No. of Injuries/ Player/yr	Other Rates
Juniors										
Spinks, 2006	Australia	P	I	12 mo	10	744 pre-school and school children (407 M, 337 F), aged 5–12 years	Any incident which occurred during physical activity and for which first aid treatment was given	1.2 1.3 M 1.1 F		
Silva, 2003	Brazil	P	DM	13 tournaments	280	258 participants in the national circuit in the under 12, 14, 16, and 18 age categories	Any consultation and/or treatment given to a player during a tournament on site			1.8 treatment/ injured player; 6.9 evaluations/ 1,000 games played
Safran, 1999	United States	P	DM	6 tournament (3 M, 3F)	137 M 96 F	720 M and 539 F participants at USTA Boys and Girls National Champions, 1996–1998	All injuries that required physical or medical assistance			18.5/100 players 37/1,000 AEs
Beachy, 1997	United States	R	MR	8 yr	146	291 M and 297 F high school players	Every time an athlete sought help it was considered a reportable injury	0.1 M 0.4 F		
Hutchinson, 1995	United States	P	DM	6 tournaments in 6 yr	304	1440 participants at the USTA Boys National, Championships 1986–1988; 1990–1992.	Any medical problem requiring physical or medical assistance			21.5/1,000 AE; 9.9/100 players
Baxter-Jones, 1993	United Kingdom	P	I	2 yr	162	156 elite players, 8–16 y	Any injury resulting in discontinuation of training and/or medical treatment		0.5	
Backx, 1991	Netherlands	P	Q	7 mo	399 (all sports)	1818 school children 8–17 y; 198 tennis players	Any physical damage caused by an accident during physical education or in any sports activities outside of school, both organized and non-organized	1.5	0.1	
Backx, 1989	Netherlands	R	Q	6 wk	791 (all sports)	7468 school children 8–17 y; 690 tennis players	Physical damage caused by a sports-related incident and reported as such by the respondent			All sports 10.6/100 participants RR tennis 0.47 RR 0.4 M RR 0.6 F
Reece, 1986	Australia	R	MR	4 yr	176	24 M + 21 F elite players at Australian Institute of Sport, aged 16–20 y, mean 17.6	Any injury that required attention from the medical officer or physiotherapist		2.5 M 2.9 F	

(*continued*)

Table 21.1 (*continued*)

Study[a]	Country	Study Design	Data Collection	Duration of Injury Surveillance	No. of Injuries	Study Population	Injury Definition	No. of Injuries/ 1,000 hr of Exposure	No. of Injuries/ Player/yr	Other Rates
Garrick, 1978	United States	P	C	2 yr	13	114 M and 136 F high school tennis players	A medical problem resulting from tennis participation necessitating removal from a practice or competitive event and/or resulting in missing a subsequent practice or competitive event		0.01 M 0.04 F	
Adults										
Veijgen (2007)	The Netherlands	P	Q	13 wk	283	1,009 amateur tennis players	Any physical symptom of a player resulting from a tennis match, practice, or unorganized tennis activity, as a result of which the player was not able to take full part in tennis for ⩾3 consecutive days	3.0	1.0	
Jayanthi et al. (2005)	United States	R	Q	1 yr	299	140 M, 388 F recreational-league players (ITN 3 to 8); mean age 46.9 yr	Any injury or pain the player had experienced in the past 12 mo preventing play for ⩾7 days or more	3.0 3.8 M 2.8 F		Prevalence, 52.9 injuries /100 players
Kühne et al. (2004)	Germany	P	Q	2 yr	335	60 competitive players, mean age 25 yr; 50 recreational players, mean age 53 yr	The injuries and problems that the player experienced during tennis		1.5	
LIS—Oldenziel & Stam (2008);	The Netherlands	P	MR	Continuous registration	2,331, extrapolated to 4,000 injury/yr	Tennis players from general population (2002–2006)	Injuries requiring treatment at an emergency department	0.05		
Stam (2004);					Extrapolated to 5,200 injury/yr	Tennis players from general population (1998–2002)		0.05		
Schoots et al. (1999)					Extrapolated to 7200 injury/yr	Tennis players from general population (1992–1996)		0.06		
OBiN—Oldenziel & Stam (2008); Schmikli et al. (1995, 2001); van Galen & Diederiks (1990)	The Netherlands	R	I	3.5 mo	Outdoor, 91 Indoor, 37 Unknown, 3	Tennis players from general population (2000–2005)	All acute and chronic injuries or ailments that developed as a result of or during sports participation	1.1 (range, 0.9–1.3) 0.9 outdoor 1.6 indoor		
				3 mo	Outdoor, 27 Indoor, 17	Tennis players from general population (1997–1998)		<0.5 Outdoor 1.0 Indoor		

				4 wk	Outdoor, 42 Indoor, 24	Outdoor, 1,216 players Indoor, 573 players (1992–1993)	Injuries or ailments newly developed as a result of or during sports participation; chronic injuries not recorded	1.2 Outdoor 2.9 Indoor		
				4 wk	Outdoor, 35 Indoor, 28	Tennis players from general population (1986–1987)		1.2 Outdoor 1.8 Indoor		
Sallis et al. (2001)		R	MR	15 yr		College players; range, 18–22 yr; 3,767 participants in all sports, including tennis	Medical problem as a result of sport participation requiring visit to training room		0.5 M 0.4 F	
Weijermans et al. (1998)	The Netherlands	P	Q	6 mo (outdoor season)	179	179 club players from 46 tennis clubs	Tennis-related problem resulting in loss of practice or match time, need for medical consultation, or negative social/economic consequences (absence from school/work)	0.1		
Routley & Valuri (1993)	Australia	P	MR	1 and 2 yr	90	General population; 338,400 tennis players	Injuries requiring treatment at the emergency department		0.0003	
Larsen (1991)	Denmark	P	Q	6 mo	33	109 M, 51 F members of a Danish tennis club (303 members); mean age 26.8 yr (range, 9–59)	Injury was self-defined as any lesion occurring as a result of tennis play (whether or not the person was able to continue play)	5.0 5.4 M 4.1 F		10.9 injury/ player/season
Lanese et al. (1990)	United States	P	DM	1 yr	10	12 M, 11 F college players, age 18–22 yr	Traumatic medical problem due to sports participation resulting in time loss from practice or competition	1.4 1.6 M 1.0 F	0.4 0.50 M 0.4 F	
Winge et al. (1989)	Denmark	P	Q	6 mo (outdoor season)	46	Elite players: 61 M, mean age 28 yr; 28 F, mean age 22 yr	Every problem that appeared in connection with tennis, handicapped the player during play, and/or required special treatment	2.3 2.7 M 1.1 F		0.5 injury/ player/season
Krause & Pottinger (1988)	Germany	R	Q	1 yr	88	78 M + 49 F elite players, age 15 to 46 yr	All tennis-related injuries from the year before (1985)		0.7	
Biener & Caluori (1976a, 1976b, 1976c)	Switzerland	R	Q	Tennis career	225	203 M, 72 F high-level competitive players; mean age 28 yr	Not reported		0.05	

AE = athlete-exposure; DM = direct monitor; F = female; I = interview; i/d = indoor tennis; ITN = international tennis number; LIS = letsel informatie systeem; M = male; MR = medical records; OBiN = Ongevallen en Bewegen in Nederland (Injuries and physical activities in the Netherlands) o/d = outdoor tennis; P = prospective; Q = questionnaire; R = retrospective.

[a] Results of the LIS and OBiN studies in different time periods have been reported by different authors.

Table 21.2 Percent comparison of injury location in tennis.

	P						
	Oldenziel & Stam (2008)	Veijgen (2007)	Kühne et al. (2004)	Sallis et al. (2001)	Safran et al. (1999)	Hutchinson et al. 1995	Winge et al. (1989)
	2331	283	335	1874 (all sports)	233	304	46
Head/trunk	***11***	***10***	***11.3***	***7.9***	***19.9***	***22***	***11***
Head/neck	9	1.1			4.2	7	
Back					12.1	12	
Upper back/chest	1	1.1	11.3	7.9			11
Lower back	1	7.8					
Abdomen					3.6	3	
Upper extremity	***29***	***36.7***	***24.9***	***23.9***	***27.7***	***27***	***45.8***
Shoulder	4	12	11.8	13.9	10.7	9	17.4
Arm	<1	2.8		5.9	5.0		4.4
Elbow	2	13.1	4.4		8.5	8	10.9
Forearm	1	2.8	5.1				2.2
Wrist/hand	21	6.0	3.6	4.1	3.5	10	10.9
Lower extremity	***60***	***53.3***	***63.6***	***65.2***	***52.5***	***51***	***39***
Pelvis/hip	<1	3.5	27.1		6.4	8	
Thigh/groin	2	8.5		13.9	9.9	21	4.3
Knee	10	12.7	7.8	12.0	5.0	2	6.5
Lower leg	10	18.0	14.6	13.2		2	4.3
Calf/Achilles tendon	7				9.2		4.3
Ankle	25	8.5	6.9	16.7	8.5	7	10.9
Foot/toes	5	2.1	7.2	9.4	13.5	11	8.7
Other	<1			3.0			4.3
Total	100	100	99.8	100	100.1	100	100.1

P = prospective; R = retrospective.
[a] Refers to the total number of overuse injuries.

2004; Veijgen 2007). The pattern of injury onset varies by injury location. Most acute injuries are found in the lower extremities and most gradual-onset, more chronic injuries are located in the upper extremities. This is not surprising, as most acute trauma such as ankle sprains, knee sprains, and muscle ruptures originate in the lower extremity. The more gradual-onset chronic repetitive strain injuries tend to affect the tendons of the shoulder, elbow, and wrist, located in the upper extremity.

Chronometry

Very little information is available related to the time when injuries occurred, such as time into practice, time of day, or time of season. In a study on badminton, squash, and tennis players, Chard & Lachmann (1987) reported that in 20% of the players, injury occurred within a few minutes of starting play. However, this was an overall figure for all three racquet sports and not specified for tennis.

What Is the Outcome?

Injury Type

A percent comparison of injury types sustained by tennis players is shown in Table 21.3. A strain is consistently the most common injury type for tennis players, whereby the severity of the injury can vary from a slight muscle strain to chronic tendinopathy. A sprain is the second most common injury type. We added a column for cramps, as the number of cramps was quite high in one study, and it is debatable whether or not cramps should be classified as an injury (under strains).

			R		
Jayanthi et al. (2005)	Krause & Pöttinger (1988)	Chard & Lachmann (1987)	Reece et al. (1986)	von Krämer. & Schmitz-Beuting (1979)	Biener and Caluori (1976a, 1976b, 1976c)
299	88	131	176	225	15
10	***19.3***	***20***	***19.3***	***16.6***	***8***
		2	2.8	3.8	6
10					2
	19.3	16	2.3	12.8	
			10.2		
			4		
41	***36.2***	***35***	***19.9***	***48.2***	***43.4***
15	27.2	9	9.1	5.7	
20	4.5	14.5	7.4	41	
			1.1		
6	4.5	7	2.3	1.5	
39	***39.8***	***45***	***60.8***	***31.1***	***48.6***
	5.7		5.7	3.4	
5	3.4		9.7		
12	9.1	19	13	4.9	
1			4.5	15.1	
5	2.3	4	5.7		
8	19.3	5.5	14.2		
8		4	8	7.7	
3	4.5	(19)[a]			
93	99.8	100	100	95.9	100

Tennis Elbow

A percentage comparison of injury rates for tennis elbow is shown in Table 21.4. The reported injury rates for tennis elbow are quite high, with percentages ranging from 37% to 57%. However, the injury definitions used were either quite broad ("Have you ever had pain on either side of the elbow which has caused discomfort or disability when playing tennis?") or tennis elbow was self-reported, without the use of an injury definition. Furthermore, all studies presented cumulative incidence rates by reporting the career incidence: the percentage of players who currently suffered from tennis elbow (or elbow pain) or had suffered from it in the past. Only one study (Carroll 1981) reported the yearly incidence and prevalence of tennis elbow (9.1% and 14.1%, respectively). These cumulative injury rates should be interpreted with caution, as they are difficult to compare with more recent studies, in which elbow injuries are presented as either a yearly incidence or as a percentage of all injuries (range, 2–20%; Table 21.2).

Knee

Three studies specifically examined anterior cruciate ligament (ACL) injuries in tennis players. Majewski et al. 2006, Susanne & Klaus (2006) reviewed the epidemiology of 7,769 athletic knee injuries that had been treated in their clinic over a 10-year period. Of these, 295 were directly related to tennis. Of the 129 patients who underwent arthroscopic evaluation, 33 (11.3%) were found to have an ACL injury. Powell et al. (1988) reported 222 racket-sport–related knee injuries. One hundred twenty-one players underwent arthroscopy, and 28 (13%) were diagnosed

Table 21.3 Percent comparison of injury type.

Study	No. of Injuries	Abrasions/ Lacerations	Contusions	Cramps	Dislocations	Fractures	Inflammation	Miscellaneous	Overuse (not specified)	Strains	Sprains	Unspecified
Oldenziel & Stam (2008)	2331	28	—	—	3	21	—	<1	—	19	26	2
Veijgen (2007)	283	0.7	0.7		0.4	1.8		5.4 (eye, 0.4; nerve, 1.1)	13.8	59.3	15.1	2.8
Kühne et al. (2004)	335	—	7.2	28.7	0.3	0.6	2.1	0.3		46.6	13.7	
Silva et al. (2003)	399		4	27.1			17.7			39.6	4.3	
Safran et al. (1999)	233	0	5.0		0.71	0.7	18.4	12.1		54.6	8.5	
Hutchinson et al. (1995)	304	8.6	3.8		0.5	1	10	3.8		55	17.1	
Winge et al. (1989)	46	5				2		5 (blisters)		14	17	
Reece et al. (1986)	176	1.1	0.6	0.6		3.5	7.0	1.2		69.2	16.9	
Biener & Caluori (1976a, 1976b, 1976c)	225					3.1		0.8 + 11.3			21.3	

Table 21.4 Comparison of tennis elbow injuries.

Study	Study Design	Data Collection	Study Population	Injury Definition	Injury Rate	Severity
Kamien (1989)	R	Q and I	260 (187 M, 73 F) active club members, age 10 to 70 yr	Have you ever had pain on either side of the elbow which has caused discomfort or disability when playing tennis?	57% career incidence	36% (33% M, 42% F) could not use arm in daily life; 59% had to stop playing tennis
Kitai et al. (1986)	Q	Q and DM	150 M members of 4 tennis clubs, mean (±SD) age 41.5 ± 11.3 yr	Any reported elbow pain was noted as tennis elbow	51% career incidence	Single episode 41 wk; if more episodes: first 13 and most recent 18 wk
Carroll (1981)	R	Q and I	74 local league players, age 17–54 yr	Self-reported tennis elbow sufferers; no injury definition given	35% career incidence	1 player had surgery
Priest et al. (1980a, 1980b)	R	Q	2,633 (1,343 M, 1,290 F) participants of a tennis school, 9–69 yr	Experienced elbow pain from playing tennis	31% career incidence	130 players received a cortisone injection
Gruchow & Pelletier (1979)	R	Q	532 (278 M, 254 F) members of a private tennis club, aged 20 to 50 y	Self-reported tennis elbow sufferers; no injury definition given	Incidence, 9.1%; prevalence, 14.1%; Career incidence, 39.7%	3 players had surgery

Career incidence = percentage of players that currently suffered from tennis elbow or had suffered from it in the past;.DM = direct monitoring; F = female; I = interview; M = male; Q = questionnaire; R = retrospective; SD = standard deviation.

with an ACL injury. Of the 19 knee injuries reported by Kühne et al. (2004), only two were ACL ruptures (10.5%). Even though ACL injuries are not as common in tennis as they are in contact sports, they do occur, and risk factors need to be identified.

Tennis Leg

Millar (1979) reviewed 720 cases of calf-muscle strain, also known as "tennis leg." In 16.2% of the cases, the injury occurred during tennis play. Unfortunately, no data regarding the population at risk were presented.

Achilles Tendon Rupture

Möller et al. (1996) examined 153 cases of total Achilles tendon rupture. Of the 98 Achilles tendon ruptures due to sports injuries, 12 occurred during tennis play (10 in men, 2 in women).

Back

The motions required in tennis include flexion, extension, and rotation of the spine, and intense tennis play is generally held to be a risk factor for low back pain (Figure 21.1). This was examined in several studies.

Saraux et al. (1999) interviewed 633 spectators at an international tennis competition and divided them into 388 tennis players (281 men, 107 women) and 245 non–tennis players (140 men, 105 women). Among the male tennis players, 17.4% reported low back pain during the past week, as compared with 18.7% of the non–tennis players. Corresponding

Figure 21.1 The motions required in serving include flexion, extension, and rotation of the spine.
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figures in women were 18.7% and 27.6%. Sciatica was not more common in tennis players than in non–tennis players (men, 7.1% vs. 4.3%; women, 7.5% vs. 9.5%). None of these differences were statistically significant. The volume of play was similar in tennis players with and without pain.

Lundin et al. (2001) investigated back pain and radiologic changes in the thoracolumbar spine in 134 former top athletes, including 28 tennis players, and 28 nonathletes of comparable age. Among the tennis players, 14 had no back pain, 5 had moderate back pain, and 9 had severe back pain. Of the nonathletes, 11 had no back pain, 8 had moderate back pain, and 9 had severe back pain. No correlation was found between back pain and the number of types of radiologic abnormalities in either group. However, a decrease in disk height during the 13-year follow-up period correlated significantly to low back pain ($P = 0.005$).

Alyas et al. 2007, Turner & Connell (2007) studied the spine of 33 asymptomatic elite adolescent tennis players (mean [±SD] age, 17.3 ± 1.7 years). Five players (15.2%) had a normal magnetic resonance imaging examination, and 28 (84.8%) had an abnormal examination. Nine players showed 10 pars lesions (3 complete fractures) and 23 patients showed signs of early facet arthropathy.

In conclusion, there is no evidence that playing tennis involves a higher risk of low back pain (with or without sciatica). However, radiologic abnormalities are common, and the disk is the structure at risk for future back pain in former players.

Stress Fractures

Maquirriain & Ghisi (2006) performed a retrospective study of the 139 players designated by the Argentine Tennis Association for medical care at their High Performance Center. The elite tennis players in their study had a 12.9% absolute risk of stress fracture during a 2-year period. The tarsal navicular bone, the spine, and the metatarsals were the most affected bones.

Goldberg & Pecora (1994) found a clinical incidence of 8% in tennis (2 injuries in 24 players) when they reviewed the medical records of stress fractures in collegiate athletes over a 3-year period. In a case series of 196 stress fractures, Iwamoto & Takeda (2003) found five fractures (2.6%) related to tennis. The proportion of stress fractures of all tennis injuries (n = 363) was 1.7%. Reece et al. 1996, Fricker, and Maguire (1986) reported five stress fractures (of 176 injuries) among 45 elite junior tennis players followed for 4 years.

Eye Injuries

Of a total of 80 athletes with sport-related eye injuries who presented to a hospital emergency department, 12.6% were caused by tennis (Pardhan, Shacklock & Weatherill 1995). Most injuries were caused by contact with the ball, and all patients required follow-up treatment or hospital admittance. A study by Barr et al. (2000) of 52 sport-related eye injuries showed that 10% were related to tennis. Of all injuries, macroscopic hyphema was the most common reason for admission (87.5%).

Time Loss

In the reported studies, time loss ranged from 5.9 to 48.5 days per injury (Biener & Caluori, 1976a, 1976b, 1976c; Winge et al. 1989; Lanese et al. 1990) and from 5.7 to 24.2 days per 1,000 hours of play (Lanese et al. 1990). Time lost from work was much less, as people are often able to continue working despite having a shoulder or ankle injury, ranging from 0 to 5 days per injury, with 16% to 20% of all injuries resulting in time lost from work (Weijermans et al. 1998; Kühne et al. 2004; Oldenziel & Stam 2008). In the LIS study (Breedveld 2003), 5% of all players visiting an emergency department from 1997 to 1999 were hospitalized for an average of 5 days. From 2002 to 2006, the percentage of players who were hospitalized after visiting an emergency department was 6%, and the average number of days in the hospital was 3.5 days (Oldenziel & Stam 2008).

Clinical Outcome

Medical Treatment

Injuries sustained while playing indoors tended to be more severe than outdoor injuries, with a higher percentage (range, 57–66% vs. 27–53%) requiring medical treatment (van Galen & Diederiks 1990; Schmikli et al. 1995, 2001; Oldenziel & Stam 2008). The percentage of injuries requiring medical treatment ranged from 27% to 60% (Biener & Caluori, 1976a, 1976b, 1976c; Breidveld 2003; Kühne et al. 2004; Stam 2004; Oldenziel & Stam 2008).

In two studies of junior tennis players (Reece et al. 1986; Hutchinson et al. 1995) injuries were relatively minor. Hutchinson et al. (1995) reported that only 1 of 1440 players required transport to the hospital (heat exhaustion). Reece et al. (1986) reported 176 injuries during a 4-year period, of which only 2 required surgical intervention. The first was a painful bipartite patella, in which the offending piece of bone was surgically removed. The second condition was a lateral meniscus injury, treated with a partial meniscectomy.

Injuries were more serious in a study of 110 competitive tennis players: 3.3% of acute and 2.2% of chronic injuries required surgery (Kühne et al. 2004). These included two ACL reconstructions, three partial meniscectomies, one meniscus repair, one Achilles tendon repair (a second Achilles tendon rupture was treated conservatively, with a cast), and one lateral ankle ligament reconstruction. This was a rerupture; three other lateral ankle ligament ruptures were treated conservatively.

Osteoarthritis of the Lower Extremities

Spector et al. (1996) retrospectively studied a cohort of 81 female former elite athletes (67 middle- and long-distance runners, and 14 tennis players), 40 to 65 years of age, recruited from original playing records, and 977 age-matched female controls from London, United Kingdom. Osteoarthritis was defined by radiologic changes (joint-space narrowing and osteophytes) in hip joints, patellofemoral joints, and tibiofibular joints. The former athletes had a greater risk of radiologic osteoarthritis at all sites. This association was strongest for the presence of osteophytes at the tibiofibular joints (odds ratio, 3.6; 95% confidence interval [CI], 1.9–6.7), at the patellofemoral joints (odds ratio, 3.5; 95% CI, 1.8–6.8), narrowing at the patellofemoral joints (odds ratio, 3.0; 95% CI, 1.2–7.7), femoral osteophytes (odds ratio, 2.5; 95% CI, 1.0–6.3), and hip joint narrowing (odds ratio, 1.6; 95% CI, 0.7–3.5), and was weakest for narrowing at the tibiofibular joints (odds ratio, 1.2; 95% CI, 0.7–1.9)). The tennis players tended to have more osteophytes at the tibiofibular joints and hip. It was concluded that weight-bearing sports-activity in women is associated with a twofold to threefold increased risk of radiologic osteoarthritis (particularly the presence of osteophytes) of the knees and hips.

Maquirriain & Ghisi (2006) studied 18 asymptomatic tennis players (17 men; mean age, 57.2 years; range, 51–76) and 18 age- and sex-matched controls (59.8 years; range, 51–76). Changes in the dominant shoulder occurred in 33% of the players, versus 11% of the controls ($P = 0.04$ by the Wilcoxon test). The group with osteoarthritis was significantly older than the players without degenerative changes ($P = 0.0008$). It was concluded that prolonged intensive tennis practice may be a predisposing factor for mild degenerative articular changes in the dominant shoulder.

Economic Cost

The direct medical costs per year in the Netherlands for patients treated for a tennis injury at an emergency department were calculated in the LIS study (Schoots et al. 1999; Stam 2004; Oldenziel & Stam 2008). The average costs per patient increased from 690 USD per year in the period 1997 to 1999 to 1800 USD in the period 2002 to 2006. The total direct medical costs increased from 4.1 million USD (1997–1999) to 6.9 million USD (2002–2006). Further study is warranted on direct and indirect medical costs for tennis injuries in other countries.

What Are the Risk Factors?

Intrinsic Factors

Age

The association between age and injury rate has been investigated in two studies (Jayanthi et al. 2005; Veijgen 2007). Injury rates appeared to be independent of age.

Sex

Studies examining the relation between injury risk and gender are presented in Table 21.5.

Four prospective cohort studies (Winge et al. 1989; Lanese et al. 1990; Safran et al. 1999; Sallis et al. 2001) compared injury rates between male and female tennis players, and showed that the injury rate was higher for the male players, but in only two studies (Winge et al. 1989; Safran et al. 1999) was this difference statistically significant. In the LIS study, there was no significant difference in the number of men as compared with women who presented with a tennis injury at an emergency department (Oldenziel & Stam 2008). The male-to-female ratio was 55:45, which is similar to the tennis participation rates of men and women in tennis in the Netherlands (Hildebrandt et al. 2004).

These results suggest that injury rates in male and female players are fairly similar, but that there might be a slight preponderance of injuries in male players.

Previous Injury

It has not been reported in tennis studies whether a previous injury is a risk factor for another injury.

Extrinsic Factors

Extrinsic risk factors for tennis injuries include volume of play, skill level, match play, playing surface, shoes, and equipment (rackets, string and balls).

Volume of Play

Veijgen (2007) found that those who played >3 hours per week had a significantly higher risk for tennis injury than those who played <3 hours per week. Weijermans et al. (1998) reported that the injured group played an average of 4.9 hours per week, whereas the noninjured group played an average of 2.1 hours per week. This difference was statistically significant in the 30-to-39-year age group ($P < 0.05$) and the 40-to-49-year age group ($P < 0.005$).

Two studies on tennis elbow noted a higher risk with an increased volume of play. Kitai et al. (1986) reported that the "average" tennis-elbow sufferer has played 8 hours weekly before the onset of pain, whereas the average pain-free player plays 5.5 hours a week. Gruchow & Pelletier (1979) noted that recreational players practicing >2 hours a day were at significantly higher risk for elbow pain than those playing <2 hours a day. In contrast, Jayanthi et al. (2005) reported that the total incidence and prevalence of all tennis-related injuries were not different among recreational players who played <4 hours a week, 4 to 6 hours a week, or >6 hours a week.

These studies suggest that an increased volume of play is likely to be a risk factor for tennis injury, but the association between volume of play and injury risk should be studied in greater detail.

Skill Level

We were able to identify only three studies that compared injury rates between players of different ability. Jayanthi et al. (2005) described the incidence and prevalence of injuries in recreational players of different skill levels, ranging from International

Table 21.5 Sex as a risk factor for tennis injuries.

Study	Study Design	Data collection	Study Duration	No. of Subjects	No. of Injuries	Injury rate per 1000 h	*P* Value or Odds Ratio	Injury Rate, Other	*P* Value
Oldenziel & Stam (2008)	P	MR	Continuous	2,331 registered cases	2,331	0.05 (55%M:45%F)	ns		
Veijgen (2007)	P	Q	13 wk	1009	283	3.0	OR (F), 0.7 (95% CI 0.6–1.0), $P = 0.053$		
Jayanthi et al. (2005)	R	Q	1 yr	140 M 388 F	299	3.75 M 2.78 F	NS		
Sallis et al. (2001)	R	MR	15 yr	3767 all sports	1874 all sports			0.456 M and 0.425 F injury/player/year	NS
Safran et al. (1999)	P	DM	6 tournaments	720 M 539 F	137 M 96 F	19/100 athletes (M)(F)	0.62	41/1,000 AEs (M) 32/1,000 AEs (F)	0.001
Lanese et al. (1990)	P	E	1 yr	12 M 11 F	6 M 4 F	1.6 M 1.0 F	0.37		
Winge et al. (1989)	R	MR	6 mo	61 M 28 F	46	2.7 M 1.1 F	P<0.05	0.64 injury/season (M)(F)	<0.05
Reece et al. (1986)	R	MR	4 yr	24 M 21 F	176			2.5 M and 3.0 F injuries/player/yr	Not reported

AE = athlete-exposure; F = female; M = male; NS = not significant; OR = odds ratio; P = prospective; R = retrospective.

Tennis Number 3 to 8. Despite trends, there were no statistical differences in overall injury incidence and prevalence rates across all skill levels. There were trends of increasing prevalence of injuries in players with higher ranking. Veijgen (2007) reported that experience (≥5 years of play) was a protective factor for tennis injuries (odds ratio, 0.7; 95% CI, 0.5–0.9; $P = 0.010$). Maquirriain & Ghisi (2006) reported that junior elite players had a higher incidence of stress fractures than professional adults (20.3%; 95% CI, 11.4–33.2; vs. 7.5%; 95% CI, 2.8–15.6; $P = 0.045$).

Match Play

Veijgen (2007) identified playing matches as a risk factor for tennis injury (tournament player: odds ratio, 4.1; 95% CI, 2.3–7.3; $P<0.01$). Because experience was identified as a protective factor (see "Skill Level" section, above), this resulted in the highest injury rates in competitive players that have played <5 years of tennis as compared with recreational players with >5 years of tennis experience.

Weijermans et al. (1998) compared injured players with noninjured players of the same age and found that significantly more injured than noninjured players played tennis competition, club championships, and tournaments (all $P < 0.01$). Furthermore, injured players considered winning and performing to be significantly more important than noninjured players ($P < 0.05$) and having fun and relaxing significantly less important ($P < 0.01$). Winge et al. (1989) found fairly similar injury rates during practice (2.2 injuries per player per 1,000 hr of training) and competition (2.4 injuries per player per 1,000 hr of match; P not significant).

These findings suggest that injury rates may be slightly higher during competition than during practice.

Equipment

Although some descriptive studies point to a relation between certain types of equipment (rackets, strings, and balls) and injury (Brody 1989; Tomosue et al. 1995; Wilson & Davis 1995; Stone et al. 1999, Vught & Safran 1999), there have been no analytical longitudinal studies that have tested this relationship.

Playing Surface

Bastholt (2000) reported on the number of medical treatments given to professional tennis players on the ATP Tour from 1995 to 1997. The relative risk of having to receive treatment while playing on a hard court as compared with grass was 0.80 ($P = 0.01$), whereas the risk of playing on a hard court as compared with clay was 2.3 ($P = 0.001$). The risk was lowest on clay as compared with grass (0.35; $P = 0.0001$). Thus, playing on either grass or hard court resulted in a higher number of treatments than playing on clay. Although "treatment" is not the same as "injury," these results suggest that the injury risk is lowest on clay, followed by grass and hard court. This may be related to the ability to slide on clay, which has been suggested to be more important than the cushioning effect of grass for the reduction of load on the locomotor system of tennis players, because of the longer braking phase and the resulting lower peak force (Nigg et al. 1986; Nigg & Segesser 1988).

Shoes

Llana et al. (2002) examined the discomfort associated with footwear worn in tennis matches; 128 male and 18 female recreational tennis players (mean age [±SD], 26 ± 8.2 years) were personally interviewed and had their tennis shoes tested. The most important finding was the significant correlation ($r = 0.19$; $P = 0.02$) between perceived incorrect arch support and plantar discomfort.

In a prospective short study with 2 months of follow-up, Nigg et al. (1986) studied 171 members of tennis clubs. Sixty-one (50 men, 18 women) reported pain and completed a medical questionnaire. Shoe, temperature, type and duration of match play, subjective assessment of shoe comfort, sole grip, and lateral stability were assessed. It was concluded that stiffness of the shoe and subjective evaluation of frictional properties of the shoe were significantly associated with pain.

Although "discomfort" and "pain" are not equivalent to "injury," it does suggest that a correct design of the shoe and outsole adapted to the surface may reduce the risk of a tennis injury.

What Are the Inciting Events?

Very little scientific information is available regarding the inciting events for tennis injuries. An ankle injury often occurs when sliding into the backhand, particularly if the foot is suddenly stopped (high friction between shoe and surface [e.g. high court temperature, loose clay, line sticking out, outsole with high friction]). In the study by Weijermans et al. (1998) one of four ankle sprains was caused by a player stepping on a ball; in 42% of the cases the player was hitting a backhand at the moment the injury occurred.

Injury Prevention

Based on the current literature review, we were unable to identify measures proven to prevent tennis injuries. There are no randomized, controlled trials or nonrandomized preventive studies available, and the limited results of the studies on risk factors for tennis injuries fail to provide a clear perspective.

Further Research

The aim of the present literature review was to provide an overview of available knowledge on the epidemiology of tennis injuries. By presenting studies with different study designs, a picture emerges that represents the current base of knowledge in this field. It is clear from the results that further studies on distribution and rate of injuries, risk factors, inciting events, and prevention of tennis injuries are needed. In particular, risk factors for injuries to the spine should be identified, particularly in the growing athlete. In addition, further research into volume of play, match play, skill level, and the relationship between age and injury risk is warranted.

Researchers should, if possible, choose a prospective study design in order to decrease the risk of recall bias. A comparison of injury rates across studies will be facilitated when similar definitions of injuries are used and are clearly stated in the studies. The injury definitions in the studies in this review can be categorized as "time loss," "medical assistance," and "tissue injury" definitions (Orchard & Seward 2002; Hägglund et al. 2005). Each definition has advantages and disadvantages and delivers its own scope of the problem of tennis injuries. A clear benefit of using a "time-loss" definition is that it will generally result in the recording of injuries that substantially affect the player's health or performance or both.

Few studies have been carried out on the reliability of injury recording systems, and this should therefore be a priority for future research (Meeuwisse & Love 1998; McManus 2000; Hägglund et al. 2005). To improve the reliability of data collection it would be recommended to develop instruction manuals that can be used by the observers.

Another important characteristic is exposure time, which is a measure of participation time in training and matches during which the player is at risk of injury. The exposure time should, if possible, be recorded individually for each player and should be taken into account when studying risk factors for tennis injuries (van Mechelen et al. 1996). However, because of practical limitations in many cases—especially in large cohort studies—estimates of exposure time may have to be used.

Finally, in order to obtain optimal results in future studies, we recommend that a consensus statement on injury definitions and data-collection procedures in studies of tennis injuries be produced.

References

Alyas, F., Turner, M. & Connell, D. (2007) MRI findings in the lumbar spines of asymptomatic, adolescent, elite tennis players. *British Journal of Sports Medicine* **41**, 836–841.

Backx, F., Beijer, H., Bol, E. & Erich, W. (1991) Injuries in high-risk persons and high-risk sports: a longitudinal study of 1818 school children. *American Journal of Sports Medicine* **19**, 124–130.

Backx, F., Erich, W., Kemper, A.B. & Verbeek, A.L. (1989) Sports injuries in school-aged children: an epidemiologic study. *American Journal of Sports Medicine* **17**: 234–240.

Barr, A., Baines, P.S., Desai, P. & MacEwen, C.J. (2000) Ocular sports injuries: the current picture. *British Journal of Sports Medicine* **34**, 456–458.

Bastholt, P. (2000) Professional tennis (ATP Tour) and number of medical treatments in relation to type of surface. *Medicine and Science in Tennis* **5**(2), 9.

Baxter-Jones, A.D., Maffulli, N. & Helms, P. (1993) Low injury rates in elite athletes. *Archives of Disease in Childhood* **68**, 130–132.

Beachy, G., Akau, C.K., Martinson, M. & Olderr, T.F. (1997) High school sports injuries: a longitudinal study at Punahou School: 1988 to 1996. *American Journal of Sports Medicine* **25**, 675–681.

Biener, K. & Caluori, P. (1976a) Sportmedizinischer Profil des Tennisspielers. *Sportarzt und Sportmedizin* **8**, 198–202.

Biener, K. & Caluori, P. (1976b) Sportmedizinischer Profil des Tennisspielers. *Sportarzt und Sportmedizin* **9**, 227–229.

Biener, K. & Caluori, P. (1976c) Sportmedizinischer Profil des Tennisspielers. *Sportarzt und Sportmedizin* **10**, 254–255.

Breedveld, K. (2003). *Rapportage Sport 2003*. Sociaal en Cultureel Planbureau, The Hague.

Brody, H. (1989) Vibration damping of tennis rackets. *International Journal of Sport Biomechanics* **5**, 451–456.

Carroll, R. (1981) Tennis elbow: incidence in local league players. *British Journal of Sports Medicine* **15**, 250–256.

Chard, M.D. & Lachmann, S.M. (1987) Racquet sports—patterns of injury presenting to a sports injury clinic. *British Journal of Sports Medicine* **21**, 150–153.

Garrick, J.G. & Requa, R.K. (1978) Injuries in high school sports. *Pediatrics* **61**, 465–469.

Goldberg, B. & Pecora, C. (1994) Stress fractures: a risk of increased training in freshmen. *Physician and Sports Medicine* **22**, 68–78.

Gruchow, H.W. & Pelletier, D. (1979) An epidemiologic study of tennis elbow: incidence, recurrence, and effectiveness of prevention strategies. *American Journal of Sports Medicine* **7**, 234–238.

Hägglund, M., Waldén, M., Bahr, R. & Ekstrand, J. (2005). Methods for epidemiological study of injuries to professional football players: developing the UEFA model. *British Journal of Sports Medicine* **39**, 340–346.

Hildebrandt, V.H., Ooijendijk, W.T.M., Stiggelbout, M. & Hopman- Rock, M. (2004) *Trendrapport bewegen en gezondheid 2002/2003.* TNO, Leiden.

Hutchinson, M.R., Laprade, R.F., Burnett, Q.M. 2nd, Moss, R. & Terpstra, J. (1995) Injury surveillance at the USTA Boys' Tennis Championships: a 6-yr study. *Medicine and Science in Sports and Exercise* **27**, 826–830.

Iwamoto, J. & Takeda, T. (2003) Stress fractures in athletes: review of 196 cases. *Journal of Orthopaedic Science* **8**, 273–278.

Jayanthi, N., Sallay, P.I., Hunker, P. & Przybylski, M. (2005) Skill-level related injuries in recreational competition tennis players. *Medicine and Science in Tennis* **10**(1), 12–15.

Kamien, M. (1989) The incidence of tennis elbow and other injuries in tennis players at the royal kings park tennis club of Western Australia from October 1983 to September 1984. *Australian Journal of Science and Medicine in Sport* **21**, 18–22.

Kitai, E., Itay, S., Ruder, A., Engel, J. & Modan, M. (1986). An epidemiological study of lateral epicondylitis (tennis elbow) in amateur male players. *Annales de Chirurgie de la Main* **5**, 113–121.

Krause, R. & Pöttinger, P. (1988) Tennisverletzungen von Leistungsspielern. *Praktische Sport-Traumatologie und Sportmedizin* **1**, 47–49.

Kühne, C.A., Zettl, R.P. & Nast-Kolb, D. (2004) [Injuries- and frequency of complaints in competitive tennis- and leisure sports]. *Sportverletzung Sportschaden* **18**, 85–89.

Lanese, R.R., Strauss, R.H., Leizman, D.J. & Rotondi, A.M. (1990) Injury and disability in matched men's and women's intercollegiate sports. *American Journal of Public Health* **80**, 1459–1462.

Larsen, J. (1991) Tennis injuries—incidence and pattern. *Ugeskrift for Laeger* **153**, 3398–3399.

Llana, S., Brizuela, G., Durá, J.V. & García, A.C. (2002) A study of the discomfort associated with tennis shoes. *Journal of Sports Sciences* **20**, 671–679.

Lundin, O., Hellström, M., Nilsson, I. & Swärd, L. (2001) Back pain and radiological changes in the thoraco-lumbar spine of athletes: a long-term follow-up. *Scandinavian Journal of Medicine and Science in Sports* **11**, 103–109.

Majewski, M., Susanne, H. & Klaus, S. (2006). Epidemiology of athletic knee injuries: a 10-year study. *Knee* **13**, 184–188.

Maquirriain, J. & Ghisi, J.P. (2006) The incidence and distribution of stress fractures in elite tennis players. *British Journal of Sports Medicine* **40**, 454–459.

McManus, A. (2000) Validation of an instrument for injury data collection in rugby union. *British Journal of Sports Medicine* **34**, 342–347.

Meeuwisse, W. & Love, E. (1998) Development, implementation, and validation of the Canadian Intercollegiate Sport Injury Registry. *Clinical Journal of Sports Medicine* **8**, 164–177.

Millar, A. P. (1979) Strains of the posterior calf musculature. *American Journal of Sports Medicine* **7**, 172–175.

Möller, A., Astron, M. & Westlin, N. (1996) Increasing incidence of Achilles tendon rupture. *Acta Orthopaedica Scandinavica* **67**, 479–481.

Nigg, B., Frederick, E.C., Hawes, M. & Luethi, S.M. (1986) Factors influencing short-term pain and injuries in tennis. *International Journal of Sport Biomechanics* **2**, 156–165.

Nigg, B. & Segesser, B. (1988) The influence of playing surfaces on the load on the locomotor system and on football and tennis injuries. *Sports Medicine* **5**, 375–385.

Oldenziel, K. & Stam, C. (2008) *Tennisblessures.* Consumer Safety Institute, Amsterdam, pp. 1–11.

Orchard, J. & Seward, H. (2002) Epidemiology of injuries in the Australian Football League, seasons 1997–2000. *British Journal of Sports Medicine* **36**, 39–44.

Otis, C.L., Crespo, M., Flygare, C.T., Johnston, P.R., Keber, A., Lloyd-Kolkin, D., Loehr, J., Martin, K., Pluim, B.M., Quinn, A., Roetert, P., Stroia, K.A. & Terry P.C. (2006). The Sony Ericsson WTA Tour 10 year age eligibility and professional development review. *British Journal of Sports Medicine* **40**, 464–468.

Pardhan, S., Shacklock, P. & Weatherill, J. (1995) Sport-related eye trauma: a survey of the presentation of eye injuries to a casualty clinic and the use of protective eye-wear. *Eye* **9**, 50–53.

Pluim, B.M., Staal, J.B., Marks, B.L., Miller, S. & Miley, D. (2007) Health benefits of tennis. *British Journal of Sports Medicine* **41**, 760–768.

Powell, J.M., Kavanagh, T.G., Kennedy, D.K., Marans, H.J. & Wright, T.A. (1988). Intra-articular knee injuries in racquet sports: a review of 128 arthroscopies. *Surgical Endoscopy* **2**, 39–43.

Priest, J.D., Braden, V. & Gerberich-Goodwin, S.G. (1980a) The elbow and tennis, part 1: an analysis of players with and without pain. *Physician and Sports Medicine* **8**, 81–91.

Priest, J.D., Braden, V. & Gerberich-Goodwin, S.G. (1980b) The elbow and tennis, part 2: study of players with pain. *Physician and Sports Medicine* **8**, 77–85.

Reece, L.A., Fricker, P.A. & Maguire, K.A. (1986) Injuries to elite young tennis players at the Australian Institute of Sports. *Australian Journal of Science and Medicine in Sport* **18**, 11–15.

Routley, V. & Valuri, J. (1993) Victorian Injury Surveillance System: adult sports injury. *Hazard* **15**, 1–16.

Safran, M.R., Hutchinson, M.R., Moss, R. & Albrandt, J. (1999) A comparison of injuries in elite boys and girls tennis players. Presented at the 9th Annual meeting of the Society for Tennis Medicine and Science, 1999, 5–7 March, 1999, Indian Wells, CA.

Sallis, R.E., Jones, K., Sunshine, S., Smith, G. & Simon, L. (2001). Comparing sports injuries in men and women. *International Journal of Sports Medicine* **22**, 420–423.

Saraux, A., Guillodo, Y., Devauchelle, V., Allain, J., Guedes, C. & Le Goff, P. (1999) Are tennis players at increased risk for low back pain and sciatica? *Revue du Rhumatisme (English ed)* **66**, 143–145.

Schmikli, S.L., Backx, F.J.G. & Bol, E. (1995) *Sportblessures nader uitgediept.* Bohn StafleuVan Loghum, Houten.

Schmikli, S.L., Backx, F.J.G. & de Wit, M.J.P. (2001) *Sportblessures driemaal geteld. Kerncijfers en trends uit landelijk onderzoek naar sportblessures in Nederland.* NOC*NSF, Arnhem, The Netherlands.

Schoots, W., Ten Hag, S., & Toet, H. (1999). In: *Trendrapport bewegen en gezondheid 1998/1999* (Hildebrandt, V.H., Ooijendijk, W.T.M., Stiggelbout, M., eds.), Koninklijke Vermande, Lelystad, pp. 97–108.

Silva, R.T., Takahashi, R., Berra, B., Cohen, M. & Matsumoto M.H. (2003). Medical assistance at the Brazilian juniors tennis circuit–a one-year prospective study. *Journal of Science and Medicine in Sport* **6**, 14–18.

Spector, T.D., Harris, P.A., Hart, D.J., Cicuttini, F.M., Nandra, D., Etherington, J., Wolman, R.L. & Doyle, D.V. (1996) Risk of osteoarthritis associated with long-term weight-bearing sports: a radiologic survey of the hips and knees in female ex-athletes and population controls. *Arthritis and Rheumatism* **39,** 988–995.

Spinks, A.B., Macpherson, A.K., Bain, C. & McClure, R.J. (2006) Injury risk from popular childhood physical activities: results from an Australian primary school cohort. *Injury Prevention* **12**, 390–394.

Stam, C. (2004) Sportblessures op de Spoedeisende hulpafdeling 1998–2002. In: *Trendrapport bewegen en gezondheid 2002/2003* (Hildebrandt, V.H., Ooijendijk, W.T.M., Stiggelbout, M. & Hopman-Rock, M, eds). TNO, Leiden, pp. 175–192.

Stone, D.A., Vught, M. & Safran, M.R. (1999) Comparison of incidence of tennis elbow in first generation and graphite composite rackets. *Medicine and Science in Tennis* **8**, 81–91.

Tomosue, R., Sugiyama, K., Yoshinari, K. & Yamamoto, K. (1995) The effectiveness of damping material in reducing impact shock in the tennis forehand drive. In: *Science and Racket Sports I* (Reilly, T., Hughes, M., & Lees, A., eds.), E&FN Spon, London, pp. 140–145.

Van Galen, W. & Diederiks, J. (1990). [Incidence of sports injuries in the Netherlands]. *Geneeskunde en Sport* **23**, 124–130.

van Mechelen, W., Twisk, J., Molendijk, A., Blom, B., Snel, J. & Kemper, H.C. (1996) Subject-related risk factors for sports injuries: a 1-yr prospective study in young adults. *Medicine and Science in Sports and Exercise* **28**, 1171–1179.

Veijgen, N.K. (2007) *Tennis injuries: a retrospective cohort study of risk factors for tennis-related injuries in the Netherlands*. Free University, Amsterdam.

von Krämer, J. & Schmitz-Beuting, J. (1979) Überlastungsschäden am Bewegungsapparat bei Tennisspielern. *Deutsche Zeitschrift für Sportmedizin* **2**, 44–46.

Weijermans, N., Backx, F.J.G. & van Mechelen, W. (1998) Blessures bij outdoor-tennis. *Geneeskunde en Sport* **3**, 95–99.

Wilson, J.F. & Davis J.S. (1995) Tennis racket shock mitigation experiments. *Journal of Biomechanical Engineering* **117**, 479–84.

Winge, S., Jørgensen, U. & Lassen Nielsen, A. (1989) Epidemiology of injuries in Danish championship tennis. *International Journal of Sports Medicine* **10**, 368–371.

Chapter 22

Triathlon

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Introduction

Triathlon made its Olympic debut as the opening event of Sydney 2000 only 19 years after first being officially recognized by the International Olympic Committee. The Olympic triathlon involves a 1.5-km lake, ocean, or river swim (Figure 22.1), a 40-km cycle ride (conducted under `drafting´ conditions where the athlete is allowed to `slipstream´ behind another rider), and a 10-km run. Competitions are also held over a variety of other distances, formats, and 5 year age-groups (see Bentley et al., 2002 and www.triathlon.org for details).

Although triathlon is increasing in popularity (O'Toole et al. 2001; Burns et al. 2003; Gosling et al. 2007), this has not been matched by a concomitant increase in the quantity and quality of triathlon injury research (Gosling et al. 2008a). It is the aim of this chapter to summarize the current state of knowledge about the distribution and determinants of injury and the efficacy of preventive measures in triathlon. Recommendations for the design of future triathlon injury research, such that the results arising from it may be more easily transferable into real-world (health and safety) gains (Finch 2006) in training and race course design, are also provided.

Fewer than 50 peer-reviewed publications on triathlon injury were obtained by our search. Although at least two longitudinal prospective studies of more than 6 weeks duration have been conducted (Vleck 2003; J. Tennant, University of North Carolina, Chapel Hill, unpublished results), both they and the largest database thus far compiled (Hiller et al. 1989, for 2,438 Olympic distance [OD] triathletes) are largely unpublished. Most of the available work is based on retrospective questionnaires, and possesses the following methodologic limitations:

- Nonrandom samples, small survey samples, low response rates, and response bias (Egermann et al., 2003; Scott 2004).
- Variation in the duration of retrospective recall required and consequent time dependent memory loss (Gabbe et al. 2003).
- Inconsistent definitions or methods of recording injury or both (Gregory 2002; Vleck 2003; Junge & Dvorak 2008) and lack of injury validation against medical records.
- Lack of differentiation in the study sample between draft-legal and draft-illegal specialists; between different athlete abilities, ages, or sexes;and between athletes specializing in training for different event distances.
- Inadequate allowance within the study design for the effects of cross-training.
- Inadequate quantification of risk factors (particularly extrinsic, training-related, ones).
- Lack of follow-up data for nonparticipants or drop-outs.

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Figure 22.1 Prerace swim training by the Portuguese National Squad, European Triathlon Championships, Lausanne, CH, August 19, 2006. Photograph by Nigel Farrow.

Data comparison between studies is also limited by the fact that injury patterns and risk of injury in triathlon may have changed over time along with changes in both the rules (International Triathlon Union [ITU] Competition rules, 2006–2008) and levels of performance (Vleck et al. 2008). The most noticeable change was the divergence of racing formats used within age group, and elite OD triathlon, at the 1995 ITU World Championships, from both having a non-drafted-cycle section to the current situation of age-group cycling remaining draft-illegal and elite OD triathlon cycling having become draft-legal.

Who Is Affected by Injury?

A summary of the published data on injury occurrence in triathlon is presented in Table 22.1. The table indicates that injury causing cessation of training for ≥1 day, reduction of training, or seeking medical aid could affect between 29% (Vleck 2003) and 91% (O'Toole et al. 1989) of athletes.

Incidence rates of 10 to 27.6 (for OD triathletes, depending on period of the year), 27.1 and 4.6 for short-distance triathletes, and 0.71±11 per 1,000 hours of exposure for Ironman (IR) triathletes, respectively, were obtained through longitudinal prospective survey by Vleck (2003), and by retrospective recall by Burns et al. (2003) and Gosling et al. (2007), respectively, as well as by Egermann et al. (2003) (data not shown). Table 22.1 indicates that differences in the extent of injury may exist between long-course and short-course triathletes (Williams et al. 1988; Vleck et al., in press), as well as between sexes (Vleck et al. 2007c) in each of these events (Vleck 2003). However, neither these differences nor whether injury rates differ with ability level (Vleck & Garbutt 1998) or between draft-legal and draft-illegal triathlon have been sufficiently investigated. The data-collection methods for the prospective studies differ, and the retrospective data do not account for differences in individual athlete exposure. It should be noted, moreover, from Table 22.1 that data regarding the extent of injury in youth and junior triathletes, athletes with a disability, or different senior age groups are entirely absent from the literature. The long-term implications of triathlon participation for pulmonary, musculoskeletal, or cardiac health (Tulloh et al. 2006; Hassan et al. 2006; Knez et al. 2007; Knez et al. 2008) are not clear.

Where Does Injury Occur?

Anatomical Location

A percent comparison of the anatomical locations (in terms of the number of total injuries, and, in brackets, the number of athletes in the study) is shown in Table 22.2 and illustrates that the studies vary both in the locations surveyed and the grouping of data. When the data of Villavicencio et al. (2006) and Clements et al. (1999) (who assessed only neck and lower back pain, and knee injury, respectively) are omitted, however, it is clear that most injuries occur

Table 22.1 Injury occurrence.[a]

Study	Study Design	Injury Definition	Subjects		Event Distance
			Men	Women	
Levy (1986a, 1986b)	R	↓Tr, CTr, Dr, Med	31	0	Not clear
Ireland & Micheli (1987)	R	Unclear	117	51	88.3% S and OD
Murphy et al. (1986)	D	Unclear	Unclear		IR (possibly same as Massimino et al. 1998)
O'Toole et al. (1987)	R	Unclear	35	11	IR (Hawaii 1984)
Massimino et al. (1988)[b]	R	Med	58	23	IR (Hawaii 1985)
Williams et al. (1988)	R	CTr; "Felt really uncomfortable in training and racing."	251	81	134 OD, 83 L, 115 S
Collins et al. (1989)[c]	R	↓Tr, CTr, Dr, Med, Non-T	197	60	OD, S, IR race finishers
O'Toole et al. (1989)	R	Athlete's judgment Given list of common OU injuries	75	20	IR
Jackson (1991)	C	Clinical case study	1	0	Mixed
Migliorini (1991)	R, D	OU; clinical diagnosis	21	3	OD (2 IR)
Korkia et al. (1994)	P	CTr ⩾1 day, CRace, CDF, T/OU	124	31	9% M and 0.6% W long; 65.2% M and 5.1% W, short
Wilk et al. (1995)	R	TR, SB, or Ru specific overuse or traumatic injury	41	31	Unclear
Manninen & Kallinen (1996)[d]	R	Unclear (mainly lower back pain)	70	22	57% IR/HM; 43% S + OD
Cipriani et al. (1998)	R	Unclear (CTr, Med?); worst injuries	44	8	Unclear (probably mixed)
Vleck & Garbutt (1998)[e]	R	↓TR, CTr, Dr, Med	12 17 87	0 0	OD
Clements et al. (1999)	R (in race)	Knee injury; ↓Tr, CTr ⩾2 days; clinical diagnosis in 18 subjects	46	12	Not stated
Fawkner et al. (1999)	P	↓Tr, CTr ⩾1 day, Dr, Med.	27	29	—
Wilk et al. (2000)	C	Clinical examination	1	0	MD
Hiller et al. (1989)	R	Unclear	1968	470	OD

Ability Level	Study Duration	Returns (%)	% Group Affected by Injury			
			All	Traumatic/ Acute	Overuse	Temp./ Fluid-Related/ Injury
Triathlon club members—unclear	1 yr	Unclear	90.3	—	—	—
29% novice, 58% average, 22% expert	Unclear	Unclear	64	—	—	—
Mixed	Unclear	Unclear	—	21	—	—
Age group—elite	Race medical report +1 yr retrospectively	4.6	M, 76; W, 73 (1 yr)	M, 22; W, 18 (1 yr)	M, 78^{C}; W, 82 (1 yr)	Unclear
Intermediate	Unclear	8	—	(22) 15	(M, 78; W, 82) 85	53.5 DH; 1 hypother.; 1 hyperther.
Age group—elite	Unclear	59.3	50.6	—	—	—
38.9% beginners, 49.4% intermediate, 11.7% elite	1 yr and 1 race	45.0	—	Excluded	49 (2.5/1,000 hr^{PS}, 4.6/1,000 hr^{C})	—
Age group—elite (15% professional)	1 year	0.20	91	—	91	—
Age group	8 wk	—	—	—	100	—
Elite—international squad	3 yr	NA	Unclear	—	—	—
Age group—elite	8 wk	21.0	37	22	41% of cases	—
Age group	1 yr	48.0	75 $^{(75\%TR,\ 27.8\%C)}$	33.3	78.9	—
1 elite	1 yr	55.0	72^{MS}	Not differentiated between		—
Mainly intermediate	Ever?	52.0	64	Unclear, but ⩾37.5 most injuries were related to overtraining		—
Elite	5 yr	71.0	41.2		75.0	—
Subelite		78	37.5		75 .0	—
Age group		66	56.3		56.3	—
7 novice, 17 club, 26 age group, 7 elite	3 yr	58	34 (34.5)	—	⩾27.8	—
—	18 wk	Unclear	39	—	—	—
Age group	Case study	NA	—	—	100	—
—	Ever	NA	No overall incidence	—	—	—

(*continued*)

Table 22.1 (*continued*)

Study	Study Design	Injury Definition	Subjects		Event Distance
			Men	Women	
Richter et al. (2007)	O	Clinical examination	0	1	IR
Burns et al. (2003)[e]	R/P	↓Tr, CTr ⩾1 day, Dr, Med, OU/T	91	40	Competitors, Australian domestic series
Egermann et al. (2003)	R	CTr/Race	588	68	IR Europe 2000
Vleck (2003)	R[e]	↓Tr, CTr, Dr, Med	7 11 7		OD OD IR
	P		5	3	OD
Sharwood (2004)	O	Clinical examination	293 579		IR (2001) IR (2002)
Shaw et al. (2004)	R	↓Tr, CTr, Dr, Soc/Ec	190	68	—
Burns et al. (2005)[e]	R	↓Tr, CTr ⩾1 day, Dr, Med	44	8	As in Burns et al. 2003
Villavicencio et al. (2006)	R	Acute event leading to CTr ⩾1 day, Dr, Med	131	56	Unclear
Gosling et al. (2007)	O race	Damage due to physical activity (race data)	213[f]/ 10, 173	6 "fun"; 5 S, 1 OD	Mixed
Tennant (2007)	R	Not clear	969		11 S, 3 OD, 2 ½ IR
Gosling et al (2008b)	O	Heat casualty	1,844 Race 1 2,000 Race 2		S
Vleck et al. (in press)[e]	R	↓Tr, CTr, Dr, Med	12 18		OD IR

C = competition-related; CDF = cessation of daily function; CRace = cessation of racing; CTR = cessation of training; CTR/Race = cessation hr = hours; hyponat = hyponatremia; hypother. = hypothermia; IR = Ironman distance; L = long distance; M = men; MD = middle dis- observational; OD = Olympic distance; P = prospective; PS = preseason; R = retrospective; Ru = Running; S = sprint; SB = swimming W = women; wk = week; yr = year; ½ IR = ½ Ironman

Superscripts refer to percentages of injuries attributed to ⩾1 discipline.

[a] Data from Chateau et al. (1 case of hypothermia), Charle (1997) (1 hand fracture in the swim). Moehrle et al. (2001), (ultraviolet potential myocardial damage (La Gerche et al. 2004) are not included.

[b] In addition, 1.0, 3.9, 6.3, 10.3, 8.2, and 10.2% of starters received postrace intravenous fluids from 1981 to 1986.

[c] Rates estimated retrospectively and unlikely to be strictly comparable because of differing recall periods.

[d] Nonsignificant tendency ($P = 0.052$) for women to exhibit more low back pain than men.

[e] Same methods of retrospective data collection & analysis used in both papers from this group.

[f] Number of race starters who presented themselves for medical assistance.

Ability Level	Study Duration	Returns (%)	% Group Affected by Injury			
			All	Traumatic/ Acute	Overuse	Temp./ Fluid-Related/ Injury
Unclear	Case study	1	—	—	—	hyponat
Novice to elite international	6 mo PS; 10 wk C	Unclear	50.4^{PS} 37.5^{C}	32	78^{PS},2.5/1,000 hr, 78^{C}, 4.6/1,000 hr	
<10, 10–12, and >12 hr	Since start?	35	74.8, 0.71±1.11/1,000 hr			
Elite Subelite Age group	5 yr	48.1–91.7	29–50			
Elite	7 mo	22–84	80.4			
Mixed	Race	All? 12 clinical diagnosis				2 hyponat
62% competitive, rest mainly lower level	3 seasons and recall for 1 season	55	62			—
Novice to elite	6 mo PS; 10 wk C	Unclear	50.4^{PS}		Unclear	—
	Lifetime	≈2.2/1,000 hr	31–67.8	13.6–62.7	31–67.8	—
Race series	2.71/1,000 race-hr	2.3% starters		28	6	7 DH, 6 temp.-related
Mixed	3 yr	24.2	90.3			
Mixed	2 races	Unclear	—	—		0.8
Elite	5 yr	75% 95%	—	43.1	72.2	—

of training or racing; D = descriptive; DH = dehydration; Dr = seeking medical aid; HM = half-marathon; hyperther. = hyperthermia; tance; Med = taking medication; MO = month; MS = musculoskeletal; NA = not applicable; OU = overuse; Non-T = nontraumatic; O = and cycling; Soc/Ec = social or economic cost; T = traumatic; temp. = temperature; TR = training-related; ↓TR = decreased training;

exposure), Mollica (1998) (case study: chronic foot compartment syndrome), or relating to muscle cramps (Lopez & Chateau 1997) or

Table 22.2 Percent comparison of injury location in triathlon.

No. of Injuries	Ireland & Micheli (1987)	Massimino et al. (1988)	Williams et al. (1988)	Collins et al. (1989)			
				All	Elite	Women	>40 Yr
	Retro	Retro	Retro		Retro		
Discipline attributed to overall	7S, 17B, 71R, 5O	5S, 20B, 58R	11S, 50B, 53R	11S, 12.5B, 62R, 8R+O, 4.1R+B, 6.5O			
Head/neck/ cervical region	—	—	6	—	—	—	—
Upper back	(5)	—	—	—	—	—	—
Lower back/back	(3.7)	LB 10	LB 17.2	4 [28.6Ba., 42.9R+O, 14.3O]	(4)	LB (8)	(0)
Shoulder/bicep	(7.5)	—	7.2	13.8 [82.6S, 13B, 4.3R+O]	(4)	(15)	11
Elbow	—	—	—	—	—	—	—
Hand/fingers	—	—	—	—	—	—	—
Forearm	—	—	—	—	—	—	—
Chest/ribs	—	—	—	—	—	—	—
Abdomen	—	—	—	—	—	—	—
Hip	—	5	6	3.6 [All R]	4	5	6
Buttocks/gluteals	—	—	—	—	—	—	—
Groin	—	7	—	2.4 [80R, 20R+O]	0	0	0
Anterior thigh/quads	(2.8) AT	—	—	1.2 [100C, Th.]	0 [Th.]	0 [Th.]	0 [Th.]
Posterior thigh/hamstrings	(3.7) PT	HS 8	—	—	—	—	—
Inner thigh	—		—	—	—	—	—
Knees[b]	(29.9)	22		25.1 [0S, 14.3B, 66.7R, 11.9R+O, 7.1O]	(29)	(23)	(23)
Hamstrings	—	8	—	1.8 [66.7R, 33.3O]	(0)	(3)	(0)
Upper Leg/tibia	—	—	—	—	—	—	—
Calf	(7.48)	—	—	5.4 [0S, 33.3B, R44.4]	(8)	(3)	(9)
Lower leg	—	—	—	6.6 [90.9R, 9.1R+O]	(13)	(13)	(3)
Achilles tendon	(0.07)	4	—	10.2 [11.8B, 88.2R,]	(13)	(5)	(23)
Ankle/foot	—	21	13.8	A 6.6 [R]	(0)	(8)	(9)
Foot /toes	(11.2)	—	—	PF 6.0 [90.9R, 9.1R+O]	(0)	PF (5)	PF (9)
Systemic	—	—	—	SF [All R]	SF (8)	SF (5)	SF (6)
ITB	—	—	—	3.0 [80.0R, 20.0 R+O]	(13)	(3)	(0)
Other	(23.3)	23	—	4.8 [37.5B, 12.5R, 50.0O]	(0)	(8)	(3)
Skin	—	—	—	—	—	—	—
Head	—	—	—	—	—	—	—
Ear	—	—	—	—	—	—	—
Collarbone	—	—	—	—	—	—	—
Upper arm	—	—	—	—	—	—	—
Shin	—	—	—	—	—	—	—
Lower limb	—	—	—	—	(13)	(3)	(0)

Hiller (1989) in O'Toole et al. (2001)	O'Toole et al. (1989)	Migliorini (1991)	Korkia et al. (1994)	Manninen & Kallinen (1996)[b]	Cipriani et al. (1998)[b]	Vleck & Garbutt (1998) (EM OD)
Retro?	Retro	—	P	Retro	Retro	Retro
—	—	3S, 23B, 64R, 10B+R	12S, 16B, 65R	LB (14)B, (43)R	Most R	34.5B, 62.1R
—	—	—	1.3	3.8	—	(16.7)
—	(9)[a]	—	—	—	—	—
		6.5	15.7 (14)			
—	(72)[b]	—	—	—	—	LB (17.9)
—	—	3.2a	1.3	8.6[All S]	7 (13)	(8.3)
—	—	—	1.3	—	—	—
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	—	—	4.2	—	(12)	—
—	—	—	—	—	—	—
—	—	—	2.9	—	—	—
—	—	—	5.8 (20IA)	1.9	(6)	AT (9.3)
—	—	—	—	—	—	—
—	—	—	—	—	—	—
(19)	14	51.6	18.6 (19)	33.3	25 (46)	(14.2)
—	—	—	—	—	(17)	(25)
—	5	Leg 22.6	—	5.7	—	—
—	—	—	—	4.8	—	(25)
—	11	—	17.1 (16)	—	12 (23)	—
(17)	—	—	—	2.9	(12)	14.3 (50)
A (6)	A 7	F 16.1	30 (27)	A 7.6	A 17, F15	A (16.7)
(7)	22	—	—	4.8	—	—
—	Sy 7	—	(3.9)	—	—	(16.7)
—	—	—	—	—	—	—
—	13	—	—	2	—	(16.7)
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	—	—	—	—	—	—

(*continued*)

Table 22.2 (*continued*)

No. of Injuries	Vleck & Garbutt (1998) (SE M OD)	Vleck & Garbutt (1998) (Ag M OD)	Burns et al. (2003, 2005)	Egermann et al. (2003)	Vleck (2003) (Squad)	Vleck (2003) (Elite F OD)
	Retro	Retro	Retro	Retro	Retro	Retro
Discipline attributed to overall	25.0B, 64.3R	15.9B, 58.7R	PS: 2.1S, 5B, 71R; C: 2S, 8B, 73R	55.8S, 54.8B, 33.7R, 5.7O	7.9S, 23B, 61R, 7.9O	28.6B, 42.9R
Head/neck/ cervical region	(0)	—	—	—	(4.2)$^{\text{OU: 33S, 33B, 33O}}$	(0)
Upper back	—	—	13$^{\text{PS}}$, 15$^{\text{C}}$	31.2 CS$^{\text{34.6OU}}$	—	(14.3)
Lower back/back	LB (29.4)$^{\text{OU}}$	LB (15.8)	—	—	(23.9)$^{\text{56B, 17R}}$	(0)
Shoulder/bicep	(14.2)$^{\text{23.5OU}}$	—	—	19.1 CS$^{\text{57.6OU}}$	(14.1)$^{\text{64.6S, 28O}}$	(14.3)
Elbow	—	—	—	4.0 CS $^{\text{34.6 OU}}$	—	—
Hand/fingers	—	—	—	—	—	—
Forearm	—	—	—	—	—	—
Chest/ribs	—	—	—	—	—	—
Abdomen	—	—	—	—	—	—
Hip	—	—	5$^{\text{PS}}$, 5$^{\text{C}}$	—	—	—
Buttocks/gluteals	—	—	—	—	—	—
Groin	—	—	—	—	—	—
Anterior thigh/quads	AT (0)	—	—	—	AT (4.2)$^{\text{33R, 33O}}$	AT (0)
Posterior thigh/hamstrings	—	—	—	—	—	—
Inner thigh	—	—	—	—	—	—
Knees[b]	(17.9)	(21.9)	15$^{\text{PS}}$ 17$^{\text{C}}$	42.7CS$^{\text{66.6OU}}$ (5)[a]	(39.4) $^{\text{34B, 56R, 17O}}$	(28.6)
Hamstrings	(11.8)	—	—	—	(15.5)$^{\text{17B, 66R, 17O}}$	(14.3)
Upper Leg/tibia	—	—	11$^{\text{PS}}$, 3$^{\text{C}}$	—	—	—
Calf	(11.8)	—	—	—	(21.1)$^{\text{7S, 80R, 13O}}$	(42.9)
Lower leg	—	—	19$^{\text{PS}}$, 17$^{\text{C}}$	—	—	—
Achilles tendon	17.9 (17.6)	(10.3)	—	27.4CS$^{\text{77.7OU}}$	22$^{\text{6B, 81R, 11O}}$	(0)
Ankle/foot	A (11.8)	—	A 16$^{\text{PS}}$, 12$^{\text{C}}$	A 22.4 CS$^{\text{59.2OU}}$(4)	A 8.5$^{\text{66R, 33O}}$	A (14.3)
Foot /toes	—	—	F14 $^{\text{PS}}$, 23$^{\text{C}}$	—	—	—
Systemic	(11.8)	—	—	—	(18.3)	(28.6)
ITB	—	—	—	—	—	—
Other	(11.8)	—	7$^{\text{PS}}$, 8$^{\text{C}}$	—	(18.3)$^{\text{7B, 53R, 40O}}$	(28.6)
Skin	—	—	—	—	—	—
Head	—	—	—	—	—	—
Ear	—	—	—	—	—	—
Collarbone	—	—	—	—	—	—
Upper arm	—	—	—	—	—	—
Shin	—	—	—	—	—	—
Lower limb	—	—	75$^{\text{PS}}$	—	—	—

A = ankle; Ag = Age-group; AT = anterior thigh; B = bicycle; Ba. = back; C = competitive season; CS = chronic symptom; E = Elite; EM = Elite N = neck; O = other; OD = Olympic distance; OU = overuse; P = prospective study; PF = plantar fasciitis; PS = preseason; PT = posterior thigh; Sy = systemic; T = toes; Th. = thigh; U = unpublished.

Case study data for external iliac endofibrosis (Speedy et al. 2000b) are not shown. Values in parentheses are the percentages of respondents affected. ages of injuries attributed to ⩾1 discipline.

[a] Data grouped, for this table, in the foot/toe and upper leg/tibia rows.

[b] Clements et al. (1999) (data not shown) stated that 22%, 65%, and 6% of knee injuries were for cycling, running, and running plus cycling, respectively.

[c] O'Toole et al. (1987) (data not shown) stated that the knee was most commonly injured, then hamstrings in men and the foot in women.

[d] Figures of both 28% injury and 32% pain given in the paper.

[e] Significant differences ($P<0.05$) between elite OD and IR male participants (particularly with regard to the extent of Achilles tendon injury (Vleck et al.,

Vleck (2003) (SE F OD)	Vleck (2003) (E F IR)	Vleck (2003) (OD MF)	Vleck (2003) (P/1,000 hr)	Villavicencio et al. (2006)	Gosling et al. (2007)	Tennant (2007)
Retro	Retro	P	P	Retro	Retro	R/P
10B, 80R		15.2S, 26B, 65.2R		LB: 81.4SR	12S, 18B, 54R	Unclear
(0)	(0)	4.2N	[0.85]	(74.2^{M} 41.1F)	—	(H 2.3, N 5.4)
(10)	(16.7)	—	—	—	—	(11.4)
(0)	(0)	(11.5)	[2.33]$^{22.7B, 18.2BR}$	67.8$^{73.1SR}$	—	—
(100)	(0)	(17.4)	[0.85]$^{12.5S}$	—	3	(17)
—	—	1	[0.21]	—	6	(2.2)
—	—	1.0Fi	[0.21]	—	5	(2.9Fi, 3.2H)
—	—	—	—	—	2	(1)
—	—	—	—	—	—	(1.1C, 3.7 R)
—	—	3.1	[0.63]^{50B,50R}	—	—	(1.1)[b]
—	—	0.63	[0.63]$^{20B, 80RR}$	—	—	(6.9)
—	—	4.2	[1.85]	—	4	
—	—	2.1	[0.42]$^{33.3SO}$	—	—	(1.8)
AT (0)	AT (16.7)	AT (8.3)	[1.69]$^{10B, 45R,10BR}$	—	—	(Q1.8)
—	—	11.5	[2.33]	—	—	—
—	—	—	[0.21]	—	—	(HS 3.9)
(20)	50)	(14.5)	[3.00]$^{15.8BR, 31.6R, 5.3O}$	MC 32	—	(22)
(10)	(16.7)	(13.0)	—	—	—	—
—	—	—	—	—	—	—
(30)	(16.7)	(8.3) NI	[1.48]$^{5-1B,2.6BO,12-8BR,33.3R}$	—	—	(5.7)
—	—	—	—	—	—	—
(30)	(16.7)	(0)	—	—	—	(8)
A (10)	A (0)	(26.9)	[0.42]^{100R}	—	—	(15)
—	—	—	[0.42]^{100R}	—	—	T (6.5) F (2.1)
(20)	(16.7)	(26.9)	—	—	—	—
—	—	—	—	—	—	—
(20.0)	(8.00)	(19.6)	—	—	—	—
—	—	—	[0.21]	—	—	—
—	—	1	[0.21]	—	—	—
—	—	1	[0.21]^{100B}	—	—	—
—	—	—	[0.85]$^{33.3B, 33.3R,33.3O}$	—	—	—
—	—	—	[1.06]	—	—	—
—	—	—	[1.27]	—	—	(7.5)
—	—	—	—	—	—	—

male; F = female; F = foot; Fi = fingers; H = hand; IA = injured athletes; ITB = iliotibial band; LB = lower back; M = male; MC = most common; Q = Quads; Retro = retrospective study; R = run; R/P = retrospective study with prospective aspects; S = swim; SE = Sub-elite; SF = stress fracture;

Values in brackets are rates per 1,000 training hours. All other values are for percentages of the total number of injuries. Superscripts refer to percent-

in press) and between elite OD male and female participants (Vleck et al. 2007a), particularly with regard to the extent of LB injury.

to the lower extremities. The areas that appear to be most at risk (**in bold**), accounting for up to 43% (Egermann et al. 2003), 23% (Korkia et al 1994), and 31% of injuries (Egermann et al. 2003), are the knee, ankle/foot, and lower back. Men and women (Collins et al. 1989; Vleck 2003; Vleck et al. 2007c), OD and IR specialists (Vleck et al., in press), and elite and non-elite triathletes (Vleck & Garbutt 1998; Shaw et al. 2004) may differ in the extent to which both these and other sites are affected (Vleck 2003), possibly as a result of differences between them in training emphasis (Vleck et al., in press), technical ability, or both. For example, iliotibial band (ITB) syndrome is commonly observed in age-group triathletes (Migliorini, S., Italian Triathlon Federation Medical Committee Chair, Stadio Olimpico, Rome, perso. comm., 2008) whereas Achilles tendon problems may occur more in elite athletes (Vleck & Garbutt 1998; Shaw et al. 2004). Again, however, the substantive data are lacking.

Environmental Location

Tables 22.1 and 22.2 also indicate the percentages of injuries sustained that were attributed to each triathlon discipline. Running, followed by cycling and then swimming, is commonly held responsible for injuries (and, specifically, for knee, lower back, and shoulder injuries, respectively [Collins et al. 1989]), but the multidiscipline nature of the sport (Millet et al. 2009), and the lack of incidence rates, make chronometry difficult to determine. Cycle and run training may exert cumulative stress (Massimino et al. 1988) influence on the risk of lower back injury, for example. Indeed, various authors (Migliorini 1991, 2000; O'Toole et al. 2001; Vleck 2003) have suggested that the triathlon cycle–run (T2) transition is a period of particular risk for both lower back and knee injury, but minimal data (Gosling et al. 2007) are available to support their assertion.

Training versus Competition Injury

It is difficult to ascertain whether injury is more of a problem during training than during competition, as the retrospective data imply (see superscripts for, e.g. Burns et al. 2003, in the "Percentage of Group Affected" column of Table 22.2 and O'Toole et al. [2001] for review). Incidence rates are practically nonexistent in the literature, and the prospective longitudinal data that support this premise in OD triathletes (Korkia et al. 1994; Vleck et al. 2002; Vleck 2003; Vleck & Bentley 2007, data not shown) are only preliminary.

When Does Injury Occur?

Injury Onset

The majority of the literature refers to what would most likely be classed (Gregory 2002) as gradual onset (presumably training-related) or overuse injury. Approximately three times as many athletes appear to be affected by overuse as are affected by acute injury (Wilk et al. 1995; Massimino et al. 1998; O'Toole et al. 1987). Whether overuse-injury prevalence differs with sex, ability level (Vleck & Garbutt 1998) or event distance specialization (Vleck et al. in press) is unclear. Whether the prevalence of sudden onset/acute injury differs between draft-legal and draft-illegal triathlon, or between male and female elite participants (since male athletes may more commonly form large cycle packs) (Vleck et al. 2008), is also unknown.

What Is the Outcome?

Injury Type

"Triathlon appears to be relatively safe for persons of all ages assuming that high risk individuals undertake health screening" (Dallam et al. 2005). As suggested above, and illustrated in Table 22.3, most reported training injuries are overuse injuries. Contusions/abrasions and blisters are amongst the most common race injuries (Gosling et al. 2007).

Time Loss

Catastrophic pulmonary injury (e.g., as a result of drowning or exercise-induced asthma [Chateau 1997; Knöpfli et al. 2007] or bee sting or jellyfish allergy [Miller 2001; Gosling et al. 2008b]), cardiac injury (Haykowsky et al. 2001; Harris et al. 2009), cycle-crash injury (Facteau 2001), and exertional heat/hydration-related injuries (e.g., coma [O'Toole et al. 1987] or respiratory and hemodynamic failure Richter et al. 1998) do occur both within training and racing, usually "as a result of failure to adjust pace within safe limits for specific environmental conditions" (O'Toole et al. 1987; Massimino et al. 1988) or inadequate implementation of technical guidelines (Mitchell 2002) or safety precautions. However, they are barely reported in the literature.

A summary of the extent to which training or racing is hindered or stopped by injury, the extent to which professional help is subsequently sought, and the type of treatment received is presented in Table 22.4. The table indicates that running, cycling, and swimming are increasingly less affected by injury (17%, 75% and 42–78% of cases [Gosling et al. 2008a]). Unfortunately, many authors (Wilk et al. 1995; Korkia et al. 1994; Cipriani et al. 1998; Wilk et al. 2000; Vleck 2003; Villavicencio et al. 2006) have pointed out that triathletes (who exhibit fewer harm-avoidance behaviors than swimmers or runners [Clingman & Hilliard 1987]) may continue to train while injured. Regrettably, the extent to which athletes modify training in the disciplines other than that in which the injury was first noticed is insufficiently documented (Vleck 2003; Vleck et al. 2003). The influence of such practice on subsequent time to full rehabilitation is unlikely to be positive (Noack, P. Swiss Olympic Medical Centre, Magglingen, Switzerland, per. comm., 2008).

Clinical Outcome

We stress that what few prospective data do exist (Vleck 2003) suggest that injury recurrence is a significant problem. This may be due to premature return to training or competition, underestimation of the severity of the primary injury, and or inadequate rehabilitation (Caine & Nassar 2005). "It would appear that getting triathletes to allow injuries to heal properly before returning to full training is the largest challenge facing the physician" (O'Toole et al. 2001).

Economic Cost

As recorded in Table 22.4, Collins et al. (1989), Cipriani et al. (1998), Egermann et al. (2003), and Vleck (2003) all reported that those who seek professional help can fall into the minority (12–48%) of injured athletes. This is despite the fact that such injuries may lead to cessation of work in 15.3% of cases (Wilk et al. 2000) and to permanent loss of function in 4.2% of cases (Korkia et al. 1994).

What Are the Risk Factors?

Intrinsic Factors

Table 22.5 summarizes the intrinsic risk factors that have been tested for correlation with or predictive value for triathlon injury. Both the correlation coefficients and the *P* values for a given relationship, when available, are given, in the "Relationship Observed" column, as superscripts to the study reference. We stress that the literature relating to putative risk factors should be interpreted cautiously, given its methodological limitations (Vleck 2003; Vleck et al. 2003; Brooks & Fuller 2006; Gosling et al. 2008b).

Table 22.5 shows that—perhaps in line with the premise that triathletes prefer to modify, rather than stop, training when injured, and avoid seeking medical attention—previous injury has consistently been found to be significantly correlated with injury occurrence (O'Toole et al. 1989; Migliorini 1991; Burns et al. 2003). Interestingly, in line with the cumulative (i.e. cross-training) stress hypothesis (Massimino et al. 1988; as discussed by Cipriani et al. 1998; O'Toole et al. 2001) some authors have obtained pilot data linking the occurrence of injuries in one anatomical site to those incurred in another (O'Toole et al. 1989; Vleck & Garbutt 1998), as well as training in more than one discipline (Vleck 2003).

Extrinsic Factors

Table 22.6 summarizes what is known about extrinsic risk factors for triathlon injury. Although increases in both training intensity and volume may be associated with injury, the research linking injury occurrence to training stress is equivocal. This is unsurprising given its lack of quality (Vleck et al., in press). Although hill repetition cycle or run work, or higher intensities of run and cycle work

Table 22.3 Percent comparison of injury types in triathlon.

Site of Injury	Murphy (1987)	O'Toole et al. (1987)	Ireland & Micheli (1987)	Massimino et al. (1988)	Hiller et al. (1989)
Neck pain	—	—	—	—	—
Contusions	—	—	4.7	—	—
Abrasions	—	—	1.9	—	—
capsule/ligament/joint	—	—	1.9	5.5	—
Tendinitis/tenosynovitis/ tendonitis					
Foot	—	tendonitis most common	All 6.9	15.3 tendinitis	(7)
Ankle	—	—	—	—	(6)[b]
Achilles	—	—	—	—	—
Supraspinatus	—	—	—	—	—
Knee	—	—	—	—	(19)[c,d]
Shin splints	—	—	13.1	8.6	—
Patellar chondromalacia	—	Maybe	4.7	3.7	—
Muscle tendon injury	—	—	—	—	—
Muscle sprain	—	—	—	—	—
Muscle strain	—	Yes	15	31.3	—
Inflammatory pain syndrome					
Iliotibial band syndrome	—	—	2.8	All 15.3, PF 8.0	(10)[d]
Patellofemoral	—	—	—		(14)[d]
Plantar fasciitis	—	—	1.9		(15)
Sesamoiditis	—	—	—	—	—
Fracture	—	—	—	—	—
Stress fracture					
Foot and ankle	—	—	4.7[f]	12.3	(10)[M]
Lower leg	—	—	4.7	—	(7)[M]
Hip/pelvis/spine	—	—	—	—	(<1)
Low back pain					
With sciatica	—	—	1.9	—	S ± BP(15)
Without sciatica	—	—	—	—	—
Not clear	—	—	—	—	(62)
Sciatica, with or without back pain	—	—	12.1	—	(15)
Unknown	—	—	12.1	—	—
Multiple	—	—	12.1	—	—
Laceration	—	—	—	—	—
Temperature-related problem					
Nonsevere	—	—	—	—	—
Severe	2	—	—	—	—
Envenomation	—	—	—	—	—
Blister	—	—	—	—	(43)
Other	8.6	JI/ bursitis	13.1	—	—

BP = back pain; F = female; JI = joint inflammation; M = male; Mc = muscle; NP = neck pain; PF = plantar fasciitis; S = sciatica, Tr = training-related; W = weight training.

Values are expressed as percent of cases unless they are enclosed in parentheses, in which case they refer to percent of athletes.

[a] Values in square brackets are for 2 sprint races in the same dataset.

[b] More common in men.

[c] patella/popliteal.

[d] More common in females.

[e] Approximate values from figure.

[f] Worst cases.

Of the three most common injuries (i.e., ankle/foot, knee and lower leg) 35% involved a strain, 25% tendinitis & 22% a tear' refers to the

O'Toole et al. (1989)	Jackson (1991)	Migliorini (1991)	Korkia et al. (1994)	Egermann et al. (2003)	Villavicencio et al. (2006)	Gosling et al. (2007)[a]
—	—	—	—	—	29SR$^{61.9\%SR:40.5\%B}$	—
—	—	—	(12)	40.9$^{82\%B, 77\%Tr}$	—	3
—	—	—	(3.4)	—	—	28 [21.3, 17.8]
—	—	(4.2)^{R}	(28)	23.2	—	—
(≈60)	Mc	—	6.9	—	—	Sprain 4 [3.3, 8.9]
60	—	—	—	—	—	—
—	—	(6.5)^{R}	—	—	—	—
—	—	(3.2)^{S}	—	—	—	—
(≈60)[e]	—	(9.7)^{Tr,d}	—	—	—	—
						—
—	—	(16.1)$^{Tr, 20\%B, 60\%R, 20\%B+R}$	—	—	—	—
—	—	—	—	26.4$^{66\%R, 14\%B, 14\%S}$	—	—
—	—	—	12.6	—	—	—
—	—	(6.5)	25.3	—	—	10 [3.3, 8.9]
—	—	(19.3)$^{Tr, 33.3\%R, 33.3\%B, 33.3\%R+B}$	16.1	—	—	—
—	—	—	—	—	—	—
—	—	(6.5)^{R}	—	—	—	—
—	—	1^{R}	—	—	—	—
—	—	—	—	9.5$^{89\%Tr, 76\%B, 12\%R}$	—	—
—	—	—	—	—	—	—
—	Yes	(13)^{R}	—	—	—	9
—	—	—	—	—	—	—
(72)[d]	—	—	—	—	(21.8+S,) (33.4) 22.9%R, 35.4%B, 39.6%O, 42%W	—
—	—	—	—	—		—
—	—	2 (6.5)^{R}	—	—	—	—
—	—	—			—	—
—	—	—	—	—		—
—	—	See paper	—	—	—	—
—	—	—	—	—	—	9 [11.5, 15.6]
—	—	—	—	—	—	4
—	—	—	—	—	—	1
—	—	—	—	—	—	4 [0, 24.4]
—	—	—	4.5	—	—	15 [27.9, 4.4]
—	—	4.2^{R}	—	—	9	15 [8.2, 15.6]

LB = low back pain; S, B, R, R+O attributed to swim, bicycle, run, other, or run + other training, respectively; SR = sports-related pain;

Superscripts denote percent of cases attributed to each discipline.

paper by Korkia et al.

Table 22.4 Injury Outcome.

Study	(Group) Injury	Activity Hindered					Activity Stopped		
		Training				Race	Training	Racing	Work
		All	Swim	Cycle	Run				
Ireland & Micheli (1987)	Worst injury	—	—	—	—	—	Moderate[a]: 22% did not stop when injured	—	—
O'Toole et al. (1987)	Race data	Severe	—	—	—	—	—	—	—
Collins et al. (1989)	All	—	—	—	—	—	Minor^{S,B} to Moderate^{R}	Minor	—
Jackson (1991)	—	—	—	—	3 wk	—	None^{S,B} to Severe^{R}	Minor^{S,B} to Severe^{R}	—
Korkia et al. (1994)	Overuse/ traumatic	(16)	(21)	(37)	(78)	(17)	Minor$^{84\%}$, Moderate$^{13\%}$ to Severe$^{3\%}$	—	≤2 days[b]
Wilk et al. (1995) : 63.9% interfered with daily activity	—	77.8^{MS}	—	—	—	33.3	—	20.8	15.3
Manninen & Kallinen (1996)	Mainly lower back	56LB	—	—	—	—	>7 Moderate, 54% Minor, 19% Severe; 56% stopped training/ racing/work	—	—
Cipriani et al. (1998)	—	—	—	—	—	—	(43)	—	—
Vleck & Garbutt (1998)	E OD M		16.7	50	41.7	—	Minor^{S,B} to Moderate^{R}	—	—
	SE OD M		16.7	75	66.7	—	Moderate^{S,B} to Severe^{R}	—	—
	Age groupM		16.7	26.2	53.6	—	Moderate^{S,B} to Severe^{R}	—	—
Clements et al. (1999)	Knee injury	—	—	—	—	—	—	—	—
Wilk et al. (2000)	—	8 wk	—	—	4 wk		Minor^{R}	—	—
Egermann et al. (2003)	—	—	—	—	—	—	—	—	—
Vleck (2003)	OD National Squad	—	—	—	—	—	E F OD Minor^{S,B} to Moderate^{R}, SE F OD or^{S,B} to Moderate^{R}, EF IR None^{S,B} to Moderate^{R}	—	—

Extended/ Permanent Loss of Function	Professional Help Sought?		Type of Treatment			Follow-up Treatment Sought	Extent to Which Injury Recurred
	No	Yes	Low Intensive	Moderate Intensive	High Intensive		
—	20.6	72.9	(13)$^{\text{PT}}$, (13)$^{\text{Pod}}$, (11)$^{\text{Chir}}$, (10)$^{\text{Oth}}$	48	—	—	(51%) worst
—	—	(24)	—	—	1.3 (3-day coma)	—	ND
—	—	31.5$^{\text{S}}$, 38$^{\text{B}}$, 35.5$^{\text{R}}$	Yes	—	—	—	26%, 42%, 47.5%
—	—	100	Yes	Yes	—	—	—
—	(49)	(9)	—	(12)	(1)	(51)	—
4.2	(34.7)	(65.3)	4.2MC	(51.4)$^{\text{Phys}}$, (41.5)$^{\text{PT}}$, (26.4)$^{\text{Mass}}$,(20.8)$^{\text{Chir}}$, (1.4)$^{\text{Acu}}$, (11.1)$^{\text{Oth}}$	(4.2)	—	—
—	—	—	—	—	—	—	—
—	—	—	(42)	—	—	—	—
—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—
	(22)	(78)	(27)$^{\text{PT}}$, (28) $^{\text{Dr/Pod}}$	—	—	—	—
No	—	Yes	Yes	PT, Mass, Orthop	—	Yes	
—	51.2	48.8	27.5	—	21.2	—	—
—	—	—	—	—	—	—	—

(*continued*)

Table 22.4 (*continued*)

Study	(Group) Injury	Activity Hindered				Activity Stopped			
		Training				Race	Training	Racing	Work
		All	Swim	Cycle	Run				
Villavicencio et al. (2006)	Acute lumbar pain	—	—	—	—	—	—	—	—
	Subacute lumbar pain	—	—	—	—	—	100	—	—
	Chronic lumbar pain	—	—	—	—	—	71.4	—	—
	Acute cervical pain	—	—	—	—	—	21.4	—	—
	Subacute cervical pain	—	—	—	—	—	80	—	—
	Chronic cervical pain	—	—	—	—	—	11.1	—	—
Gosling et al. (2007)		—	—	—	—	—	None[S], Moderate[B] to Severe[R]	—	—
Vleck et al. (in press)[b] IR & OD		—	—	—	—	—	OD Minor[S], Mod[B], Severe[R]; IR Minor[S], Moderate[B], Moderate[R]	—	—

Acu = seen by acupuncturist; amb = ambulance retrieval; Chir = seen by chiropractor; Cons Ther = conservative therapy; E = elite; off; MS = musculoskeletal; ND = not determined; OD = Olympic distance; Orthop = seen by orthopaedic specialist; Oth = seen by and running, respectively; SE = subelite; Severe = >21 days off.

[a] Massimino et al. (1996) reported (data not shown), that 19% of IR participants required medical assistance (57% minor, 4 athletes

[b] Vleck et al. (in press): OD took more time off because of run injury than IR but had less injury recurrence, though the same proportion of

(Vleck 2003), may be more likely than other types of training to engender the occurrence of overuse injury, little quality investigation of whether this is the case has taken place.

What Are the Inciting Events?

The inciting events for injury that should be addressed from a risk-management aspect, include water and air temperature for heat-related injuries (Dallam et al. 2005) and both cycling falls (Migliorini 2000) and collisions (Gosling et al. 2007) for hazard-related injuries. The overall likelihood of injury may also rise as the athlete becomes increasingly fatigued over the duration of an event (Dallam et al. 2005; Gosling et al. 2007), but this has yet to be quantified. Vleck (2003) in a 7-month prospective longitudinal study of British National Squad OD triathletes, also procured preliminary data to suggest that injury may be engendered by (individual specific) inappropriate increases in training load and or stress:recovery ratio.

Injury Prevention

Notwithstanding the dearth of high-quality research, the main preventive measures for injury

Extended/ Permanent Loss of Function	Professional Help Sought?		Type of Treatment			Follow-up Treatment Sought	Extent to Which Injury Recurred
	No	Yes	Low Intensive	Moderate Intensive	High Intensive		
—	18.8	28	—	—	—	—	—
—	0	100	100[Cons Ther]	—	0	—	—
—	0	100	100[Cons Ther]	50[PT]	—	—	—
—	21.4	50	50	50	—	—	—
—	3.6	21.4	100[Cons Ther]	100[medic/ PT]	—	—	—
—	—	100	100[Cons Ther]	—	—	—	—
—	—	54 finished	100[a], 6%[medic]	3.3%[amb]	—	—	—

LB = lower back; M = male; Mass = seen by massage therapist; medic = medication; Minor = <7days off; Moderate = 7–21 days other; P = seen by physician; Pod = seen by podiatrist; PT = seen by physical therapist; S, B, R = attributed to swimming, cycling,

hospitalised, 1% hypo/ hyper—thermia, 53.5 % dehydration.
both (16.7%) modified rather than stopped their training when injured.

that have been implemented in the sport thus far include:

- The use of ambient temperature of 35°C and wet bulb globe temperature (taking temperature, radiant heat and humidity into account) between 29.1–31.0° as an indicator of need to suspend the event, as well as restrictions to or obligatory use of swimming wetsuits according to water temperature, athlete age group, and estimated time in the water (ITU Events Organisers Manuals, Part 3: Technical, 2007).
- Technical guidelines (ITU Events Organisers Manuals, Part 3, Technical, 2007) relating to swim, cycle, and run course design (e.g., minimum allowable buoy visibility in the swim, obligatory use of cycle helmets, closing of most cycle courses to outside traffic, and terrain).
- Medical guidelines (ITU Operations Manual 2008) relating to maximum allowable numbers of competitors; competitor: support staff ratios, obligatory fluid and electrolyte provision, and freedom of access of medical support staff to the race course (Miller 2001; Speedy et al. 2000a; Dallam et al. 2005).

These precautions aim to minimize the risk of thermal- (Gosling et al. 2008a) and collision-related (Dallam et al. 2005) acute injury, as well

Table 22.5 Intrinsic risk factors for injury assessed in the triathlon injury literature.

Injury Variable	Intrinsic Risk Factor	Relationship Observed	Relationship Not Observed
Overuse injury occurrence	Sex	(Anatomical location) Vleck (2003), Vleck & Bentley (2007)[a]	Collins et al. (1989), Villavicencio et al. (2006)[BP], Williams et al. (1988) Villavicencio et al. (2006), Korkia et al (1994), Manninen & Kallinen (1996)[LB], Egermann et al. (2003).
Injury occurrence	Age	Egermann et al. (2003)	Collins et al. (1989), Egermann et al. (2003)
	Height		Collins et al. (1989), Vleck & Garbutt (1998)
	Bodymass index		Collins et al. (1989), Vleck & Garbutt (1998), Korkia et al. (1994), Villavicencio et al. (2006)
	Foot type, orthopaedic problems	Burns et al. (2005)[4× risk of over-use injury in competition period with supinated foot type]	Vleck & Garbutt (1998)
	Diet		Vleck & Garbutt (1998)[b]
Injury incidence	Performance level	Egermann et al. (2003)	
Overuse injury incidence	Initial sporting background	Williams et al. (1988)	Collins et al. (1989)
	Training in other sports	Collins et al. (1989)*	
	Athletic status		Collins et al. (1989), Villavicencio et al. (2006)[BP]
Injury to specific anatomical site	Personal best time		Vleck & Garbutt (1998)[OD: T,S,B,R]
Injury incidence	Athlete ability level	Shaw et al. (2004), Egermann et al. (2003)	Korkia et al. (1994), Vleck & Garbutt (1998)[(for anatomical location)]
Injury incidence	Years of competitive experience	Korkia et al. (1994), Williams (1998), Egermann et al. (2003)	Villavicencio et al. (2006), Vleck & Garbutt (1998).
Presenting for medical aid in race (yes/no)		Gosling et al. (2007)	
Low back pain or neck pain	Number of triathlons participated in	Villavicencio et al. (2006)[BP**]	Villavicencio et al. (2006)[NP], Collins et al. (1989)[All]
Injury occurrence	Sporting background	Williams et al. (1988)	Vleck & Garbutt (1998)
	Years of competitive experience	Burns et al. (2003)[R], Williams (1998)[T] (0.17***)	Vleck (2003) (R)[S,B,R,elite OD] men
	Main competitive distance		Korkia et al. (1994)
Injury incidence	Level reached in single sport		Vleck (2003)[Retro]
Cycle njury	Cycle gear ratio/crank length		Massimino et al. (1988), Vleck & Garbutt (1998)

Overuse-injury incidence	Position on cycle/degree of trunk flexion on cycle		Vleck & Garbutt (1998), Manninen & Kallinen (1996) LB
	Use of and type of clipless pedals		Vleck & Garbutt (1998)
	Cycle cadence	Vleck & Garbutt (1998)	Massimino et al. (1988)
	Psychological state/total mood disturbance (basic analysis)/DH	(DH) Fawkner et al. (1999)[c]	Vleck & Garbutt (1998)
	Restless sleeper, restless sleep, health worries		Vleck & Garbutt (1998)
	Orthopedic problems		Vleck & Garbutt (1998)
Plantar fasciitis	Faulty running-shoe construction	Wilk et al. (2000)[d]	
Injury incidence	Previous injury	O'Toole et al. (1989), Burns et al. (2003), Migliorini (1991), Korkia***	Manninen & Kallinen (1996)[e]
LB pain, neck pain		Villavicencio et al. (2006)***	
Calf	Achilles tendon, hamstring, knee and LB injury	Vleck & Garbutt (1998)*, **, & ***	

A = ankle; Ach = Achilles tendon; B = biking; BP = back pain; DH = daily hassles; F = foot; K = knee; LB = lower back; OD = Olympic distance; PF = plantar fasciitis; R = running; Retro = retrospective study; S = swimming; T = triathlon.

[a] Lumbar pain linked with prior foot, ankle or knee injury,

[b] Very limited data. Potential links between diet/disordered eating (Hoch et al. 2007)/occurrence of female athlete triad & triathlon injury have not yet been investigated.

[c] *r* value not given because calculated for a three sport sample.

[d] Previous lower limb pain was not linked to the onset of lower back pain.

[e] Previous lower limb pain was not linked to the onset of lower back pain

*P < 0.05 **P < 0.02 ***P < 0.01.

Table 22.6 Extrinsic risk factors for triathlon injury.

Injury Variable	Extrinsic Risk Factor	Relationship Observed	Relationship Not Observed
Injury incidence[a]	Stretching practice	[Negative,] Massimino et al. (1988)[A, Ach (before bike and after swim)]	Massimino et al. (1988), Ireland & Micheli (1987), O'Toole et al. (1989), Massimino (1998)
Number of injuries	Warm-up/cool-down practice		Ireland & Micheli (1987), Burns et al. (2003), Vleck & Garbutt (1998), Korkia et al. (1994)
Overuse-injury incidence[a]	Number of races/season		Villavicencio et al. (2006)[CP]
	Degree and specificity of coaching and feedback		Collins et al. (1989), Vleck & Garbutt (1998) (not detailed) , Egermann et al. (2003) (yes/no)
Injury	Presence of medical care (yes/no)		Egermann et al. (2003)
Overuse-injury Incidence[a]	Race distance trained for	(for anatomical location) Vleck et al. (in press) for IR vs. OD	Vleck et al. (in press), Vleck (2003) (F)
Injury incidence[a]	Training mileage	Burns et al. (2003)	Massimino et al. (1988)[KI], Korkia et al. (1994), O'Toole et al. (1989)
Injury incidence[a]	Training time	Egermann et al. (2003)[T], Shaw et al. (2004)[T, B, R], Gosling et al. (2007)$^{F=3.09**}$	Villavicencio et al. (2006)[cp], Ireland & Micheli (1987)[SBR]; Korkia et al. (1994)[SBR], Shaw et al. (2004)[S], Murphy et al. (1986)[TSBR]
Number of cycling injuries	Time spent cycling	Vleck & Garbutt (1998)$^{b,\ r=0.28***}$ Tennant (2007)***[leg injuy]	
Number of cycling injuries	Time spent running	Vleck & Garbutt (1998)$^{R,\ r=0.26***}$	
Injury incidence[a]	Percent training time spent in each discipline		Ireland & Micheli (1987)
Injury incidence[a]	Number of triathlon workouts per week	Vleck & Garbutt (1998)$^{RI,\ r=0.25*}$	Korkia et al. (1994)
Number of run injuries	Number of run sessions per week	Vleck & Garbutt (1998), $^{r=0.23*}$	
Number of cycling injuries	Training distance		O'Toole et al. (1989)a IR, Ireland & Micheli (1987); Korkia et al. (1994), Collins et al. (1989), Egermann et al. (2003)
Number of run injuries	Swimming distance	Vleck & Garbutt (1998) $^{r=0.34**}$	
Knee-injury incidence[a]	Mileage for week before event		Massimino et al. (1988)
Number of injuries	Weekly cycling distance	Williams et al. (1988)$^{r=0.14**}$	
Number of run injuries		Vleck & Garbutt (1998)$^{r=0.25*}$	
Overuse-injury incidence[a]	Cycling cadence trained at		Massimino et al. (1988), Vleck & Garbutt (1998)
Number of injuries	Higher preseason running mileage	Burns et al. (2003)	
	Time out of seat during training sessions		Massimino et al. (1988)

Number of cycling injuries	Cycling over distance, pace, cadence		Massimino et al. (1988)
Injury incidence[a]	Pace/intensity (not in detail)	Vleck (2003) (R) $^{(\text{cycle work})***}$, Massimino et al. (1988) [Ank, Ach]	Massimino et al. (1988)[K], Korkia et al. (1994), O'Toole et al. (1989)
Injury incidence[a]	Average time doing intervals, hard, moderate, easy, and hill training in all disciplines combined		Korkia et al. (1994)
Injury incidence[a]	Increase in training load	Vleck (2003) (P)	Korkia et al. (1994) P.
Number of injuries	Number of cycling or running falls	Egermann et al. (2003)	
Incidence of swimming injuries	Over-distance swim work, fartlek, hypoxic, kick, pull in swim		Massimino et al. (1988)
Number of cycling injuries	↑ Cycling over-distance work		Massimino et al. (1988)
Number of injuries	Speed cycle session time Total time spent doing speed cycle work in race week without taper	Vleck (2003) (R) $^{*\text{ to }***\ r=0.29\text{–}0.60}$	
Foot, ankle, Achilles injury	Cycled faster		Massimino et al. (1988)
Number of injuries	↑ Number of other cycle sessions	Vleck (2003) (R)$^{r=0.92*}$	
	↑ Percent of time spent doing cycle interval work	Vleck (2003) (R)$^{r=0.92*}$	
Foot, ankle, Achilles injury	↑ Other (i.e., not long, hill repetition, or speed) cycle training	Vleck (2003) (R)$^{r=0.35*}$	
Number of injuries	↑ Percent of time spent and number of sessions spent doing cycle hill repetitions	Vleck (2003) (R) $^{r=-0.44,\ -0.39*}$	Massimino et al. (1988)
	↑ Percent of time spent and number: run hill repetitions work	Vleck (2003) (R)$^{r=-0.66=0.91***}$	
	↑ Percent of time spent: quality run work/track work	Vleck (2003) (R)$^{r=0.66\text{ M},\ -0.91\text{F}***}$	Massimino et al. (1988)[R]

(*continued*)

Table 22.6 (*continued*)

Injury Variable	Extrinsic Risk Factor	Relationship Observed	Relationship Not Observed
Injury incidence[a]	Combined intensity work for all three disciplines		Korkia et al. (1994)
	↑Number of run speed sessions	Vleck (2003) (R)$^{r=0.56*\ (IR)}$	
	↑ Weighted training combined cycle and run training time in intensity levels 3 to 5 of 5 (with 5 being the highest intensity)	Vleck (2003) (P)*	
	Individual specific calculated training stress: recovery index		
	↑ Long run′ session time	Vleck (2003) (R)$^{r=0.86\ SE\ OD\ F*}$	
	↑ Number of “other” run sessions	Vleck (2003) (R) $^{r=0.63\ OD\ F**}$	
Number of injuries	“Cool down” practice (yes/no)		Korkia et al. (1994)
Injury/Knee injury incidence[a]	Training sequence		Massimino et al. (1988), Korkia et al. (1994)
Overuse injury incidence[a]	Back—to—back— (cycle run) “transition” training (yes/no)		Vleck & Garbutt, 1998
	Training in other sports	Collins et al. (1989)*	
	Strength training (yes/no)		Korkia et al. (1994), Collins et al. (1989)
	Warm-down/ stretching after training		Vleck & Garbutt (1998)
Hyponatremia[c]	Use of nonsteroidal anti-inflammatory drugs	Wharam et al. (2006) (P)	
↑ Foot and knee injury	Running mileage	Tennant (2007) **	

A = ankle; Ach = Achilles tendon; B = bicycling; CP = cervical pain; F = foot; I = injury; II = injury incidence; IR = Ironman athletes; K = knee; KI = knee injury; NI = number of injuries; OD = Olympic distance athletes; OUI = overuse-injury incidence; P = prospective study; PF = plantar fasciitis; R = retrospective study; R = running; S = swimming; T = triathlon.

* $P<0.05$.

** $P<0.02$.

*** $P<0.01$.

[a]Unless a prospective study, most “incidence” data actually refer to “incidence proportions.”

[b] Some indication of a gender, age, event distance and or athlete ability/experience effect seen in this study.

[c] Note: Speedy (2006). Fluid strategy decreased incidence of hyponatremia.

as to maximize the efficiency of injury aftercare. Unfortunately, the author is not aware of any internationally implemented sport-specific guidelines for athletes or coaches regarding either the potential cumulative risks for injury of cross-training (e.g., of repetitive cycle–run transition training for knee and lower back injury [Vleck et al. in press]) or the potential negative consequences for successful rehabilitation of the athlete continuing to train in one, two, or all three triathlon disciplines while injured. The potential injury risks of such behavior are perhaps less intuitively obvious to the athlete or coach than those occasioned by abrupt changes in training intensity or volume, hill running (Migliorini 2000; and Table 22.6), or by insufficient attention being given to the development of technical ability (Edbrooke 2003; Migliorini 2000; O'Toole et al. 2001).

It is stressed, however, that the triathlon injury literature can only be considered to be in its very early stages and that *no* rigorous scientific study of the effectiveness of either the above guidelines (e.g., with regard to what water temperature, humidity, and environmental temperature limits are actually safe [Dallam et al. 2005; Gosling et al. 2008b), or any other potential preventive measures for injury, has yet been conducted.

Further Research

It is suggested that the first step toward improvement of the level of information that is available to guide triathletes and their coaches toward a less injury-prone future is first to form, with Governing Body support, a triathlon-specific (Batt et al. 2004) consensus statement (Fuller et al. 2006, 2007a) for definition and recording of race-related injuries. Ideally, the registry system arising from such work would be subsequently implemented within a large-scale prospective longitudinal survey of ITU-sanctioned events (in a manner similar to that of the International Exercise-Associated Hyponatremia Registry of Hew-Butler et al. [2008] or the Sport Safe Australian Sports Injury Data Dictionary of Finch et al. [2007]). Central collation of the data so obtained could allow analysis of how to lessen injury risk through, for example, improvements in course design (Finch 2006).

For the potential value of such a surveillance system to be increased, it should include sufficient information for it to be also usable within triathlon training and injury research. This would require:

- Marked improvement in the detail and accuracy of quantification of overall (i.e., weighted for training mode), and discipline specific, training stress (Vleck, 2003; Vleck et al. in press).
- Development of valid methods of determining the extent of subsequent training modification within, and in other disciplines than, the one in which injury originated.
- Development of valid methods of monitoring injury recurrence (Fuller et al. 2007b).

Regrettably, a search of the current medical literature reveals that it still fails to produce a study examining the safety or injury risk of youth participation in triathlon (Dallam et al. 2005). The author suggests that the most important target for such training-related research, with implications for the long-term future of both the sport and the athletes who participate in it, is determination of the effects of triathlon training on musculoskeletal health both at a young age (American Academy of Paediatrics Committee on Sports Medicine and Fitness 1996; Emery 2005; Mountjoy et al. 2008) and in the long term (Mühlbauer et al. 2000; Shellock et al. 2003; Dallam et al. 2005), through an international prospective longitudinal cohort study that is, again, supported by the sport's Governing Bodies.

It is strongly urged that a collaborative research team of race organizers, technical officials, coaches, athletes, medical support staff, and researchers working at both the grass-roots and the top end of the sport be established, for an adequate database of injury data to be compiled and used to drive continuous improvement (Fuller 2007) in triathlon training and competition practice, as well as education of athletes, coaches, and both technical and medical staff (Shellock et al. 2003; Fuller 2007; Troy et al. 2003).

For triathlon-injury research to efficiently advance toward injury-prevention practice (Finch 2006; Gosling et al. 2008a), a change in attitude is required; triathlon must be seen to be more than the sum of the sports of which it is made up. Moreover, future investigation of the potential injury risks of triathlon cross-training and racing should use an integrated "methodology and analysis strategy that takes the cyclic [multifactorial] nature of changing risk factors into account to create a dynamic and recursive picture of etiology" (Meeuwisse et al. 2007).

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References

American Academy of Paediatrics, Committee on Sports Medicine and Fitness (1996). Triathlon participation by Children and Adolescents. *Pediatrics* **98**(3), 511–512.

Batt, M.E., Jacques, R. & Stone, M. (2004) Preparticipation examination (screening): practical issues as determined by sport. *Clinical Journal of Sports Medicine* **14**, 178–182.

Bentley, D.J., Millet G.P., Vleck V.E. & McNaughton, L.R (2002) Specific aspects of contemporary triathlon: implications for physiological analysis and performance. *Sports Medicine* **32**(6), 345–359.

Brooks J.H.M. & Fuller, C.W. (2006) The influence of methodological issues on the results and conclusions from epidemiological studies of sports injuries: illustrative examples. *Sports Medicine* **36**(6), 459–472.

Burns J., Keenan A.M. & Redmond, A.C. (2003) Factors associated with triathlon-related overuse injuries. *Journal of Orthopaedic and Sports Physical Therapy* **33**(4), 177–184.

Burns J., Keenan A.-M. & Redmond, A. (2005) Foot type and overuse injury in triathletes. *Journal of the American Podiatric Medical Association* **95**(3), 235–241.

Caine, D. & Nassar, L. (2005). Gymnastics Injuries. In: *Epidemiology of Pediatric Sports Injuries: Individual Sports.* Vol. 48 of *Medicine and Science in Sport* (Caine, D.J. & Maffuli, N., eds.), Basel, Karger, pp. 18–58.

Charles, C. (1997) Suivi medical du "France Iron Tour": comparatif 1996–1997. *Le Spécialiste de Médicine du Sport* **10**, 38–39.

Chateau, P. (1997) Bilan médical du triathlon de Nice 1997. *Le Spécialiste de Médicine du Sport* **10**, 40.

Cipriani, D.J., Swartz, J.D. & Hodgson C.M. (1998) Triathlon and the multisport athlete. *Journal of the American Podiatric Medical Association* **27**(1), 42–50.

Clements, K., Yates, B. & Curran, M. (1999) The prevalence of chronic knee injury in triathletes. *British Journal of Sports Medicine* **33**(3), 214–216.

Clingman, J.M. & Hilliard, D.V. (1987) Some personality characteristics of the super-adherer: following those who go beyond fitness. *Journal of Sport Behaviour* **10**(3), 123–135.

Collins, K, Wagner M., Peterson, K.P. & Storey, M. (1989) Overuse injuries in triathletes: a study of the 1986 Seafair Triathlon. *American Journal of Sports Medicine* **17**(5), 675–680.

Dallam, G.M., Jonas, S. & Miller, T.K. (2005) Medical considerations in triathlon. *Sports Medicine* **35**(2), 143–161.

Edbrooke, T. (2003) Injury prevention for triathlon. *NSMI Select.* National Sports Medicine Institute of the UK, Charterhouse Square, UK.

Egermann M., Brocai, D., Lill, C.A. & Schmitt, H. (2003) Analysis of injuries in long-distance triathletes. *International Journal of Sports Medicine* **24**, 271–276.

Emery, C.A. (2005) Injury prevention and future research. In: *Epidemiology of Pediatric Sports Injuries: Team Sports.* Vol. 49 of *Medicine and Science in Sport* (Caine, D.J. & Maffuli, N., eds.), Basel, Karger, pp. 170–191.

Facteau, S (2001). Ironman North America adds Perry Rendina Award. URL http://www.duathlon.com/articles/1022 [accessed on July 30, 2008]

Fawkner, H.J., McMurrary, N.E. & Summers, J.J. (1999) Athletic injury and minor life events: a prospective study. *Journal of Science and Medicine in Sport* **2**(2), 117–124.

Finch, C. (2006) A new framework for research leading to sports injury prevention. *Journal of Science and Medicine in Sport* **9**(1), 3–9.

Finch, C., Harrison, J., Harvey, D., Burns, R. & Williams, J. (2007). Australian Sports Injury Data Working Party. Australian sports injury data dictionary: Guidelines for injury data collection and classification for the prevention and control of injury in sport and recreation. 1998 Available at: http://www.sma.org.au/information/ssdatadict.asp. Accessed 18th March, 2007.

Fuller, C.W. (2007). Managing the risk of injury in sport. *Clinical Journal of Sports Medicine* **17**(3), 182–185.

Fuller, C.W., Molloy, M.G., Bagate, C., Bahr, R., Brooks, J.H.M., Donson, H., Kemp, S.P.T., McCrory, P., McIntosh, A.S., Meeuwisse, W.H., Quarrie, K.L., Raftery, M. & Wiley, P. (2006) Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Clinical Journal of Sports Medicine* **16**, 97–106.

Fuller, C.W., Molloy, M.G., Bagate, C., Bahr, R., Brooks, J.H.M., Danson, H., Kemp, S.P.T., McCrory, P., McIntosh, A.S., Meeuwisse, W.H., Quarrie, K.L., Raftery, M. & Wiley, P. (2007a) Consensus statement on injury definitions and data collection procedures for studies of injuries in rugby union. *British Journal of Sports Medicine* **41**, 328–331.

Fuller, C.W., Bahr, R., Dick, R.W. & Meeuwisse, W.H. (2007b) A framework for recording recurrences, reinjuries, and exacerbations in injury surveillance. *Clinical Journal of Sport Medicine* **17**(3), 197–128.

Gabbe, B.J., Finch, C.F., Bennell, K.L. & Wajswelner, H. (2003) How valid is a self reported 12 month sports injury history? *British Journal of Sports Medicine* **37,** 545–547.

Gosling, C., Gabbe, B., McGivern, J. & Forbes, A. (2007) The profile of triathlon injuries presenting for treatment during a triathlon race series. *Presented at the VIIth Australian Conference of Science and Medicine in Sport, incorporating the Vth National Sports Injury Prevention Conference. "Be Active '07."* October 13–16, 2007. Adelaide, Australia.

Gosling, C.M., Gabbe, B.J. & Forbes, A.B. (2008a) Triathlon related musculoskeletal injuries: the status of injury prevention knowledge. *Journal of Science and Medicine in Sport* **11,** 396–406.

Gosling, C., Gabbe, B.J., McGivern, J. & Forbes, A.B. (2008b) The incidence of heat casualties in sprint triathlon: the tale of two Melbourne race events. *Journal of Science and Medicine in Sport* **11**(1), 52–57.

Gregory, P.L. (2002) Overuse injury—an overused term? *British Journal of Sports Medicine* **36**, 82–83.

Harris, K.M., Henry, J.T., Rohman, E., Haas, T.S., Hodges, J., Roberts, W.O. & Maron, B.J. (2009). Sudden death risk associated with United States triathlon competition. *Journal of the American College of Cardiology* 53:A300.

Hassan, M.Y., Noakes, T.D., Berlyn, P., Shave, R. & George, K. (2006). Preload maintenance protects against a depression in left ventricular systolic, but not diastolic, function immediately after ultraendurance exercise. *British Journal of Sports Medicine* 40, 536–540.

Haykowsky, M., Welsh, R., Humen, D., Warburton, D. & Taylor, D. (2001) Impaired left ventricular systolic function after a half-ironman race. *Canadian Journal of Cardiology* **17**(6), 687–90.

Hew-Butler, T., Ayus, J.C., Kipps, C., Maughan, R.J., Meeuwisse, W.H., Page, A.J., Reid, S.A., Rehrer, N.J., Roberts, W.O., Rogers, I.R., Rosner, M.H., Siegel, A.J., Speedy, D.B., Stuempfle, K.J., Verbalis, J.G., Weschler, L.B. & Wharam, P. (2008) Statement of the Second International Exercise-Associated Hyponatremia Consensus Development Conference, New Zealand, 2007. *Clinical Journal of Sport Medicine* **18**(2), 111–121.

Hiller, W.D.B., O'Toole, M.L. & Douglas, P.S. (Unpublished data, 1989). Cited in O'Toole, M.L., Miller, T.K., & Hiller, W.D.B. (2001). Triathlon. In: Sports Injuries (FU, F.H. & Stone, D.A. eds.), Lippincott Williams & Wilkins, Philadelphia, pp. 778–790.

Hoch, A.Z., Stavrakos, J.E. & Schimke, J.E. (2007) Prevalence of female athlete triad characteristics in a club triathlon team. *Archives of Physical Medicine and Rehabilitation* **88**, 681–682.

ITU Competition Rules (2006–2008). URL http://www.triathlon.org/?call=TVRRNA==&keep=sh [accessed on June 7, 2009]

ITU Events Organisers Manuals, Part 3: Technical (2007). URL http://www2.triathlon.org/EO%20Manual/EOM_07edition-part3-technical.pdf?ts=1244381625 [accessed on June 7, 2009] Cited in Murphy (1987)

Ireland, M.L. & Micheli, L.J. (1987) Triathletes: biographic data, training, and injury patterns. *Annals of Sports Medicine* **3**, 117–20.

Jackson, D.L. (1991). Stress fracture of the femur: use a bone scan to distinguish it from a muscle injury. *Physician and Sportsmedicine* **19**(7), 39–42.

Junge, A. & Dvorak J. (2008) Influence of definition and data collection on the incidence of injuries in football. *American Journal of Sports Medicine* **28**(5), S40.

Knez, W.L., Jenkins, D.G. & Coombes, J.S. (2007) Oxidative stress in half and full Ironman triathletes. *Medicine and Science in Sports and Exercise* **39**(2), 283–288.

Knez, W.L., Sharman, J.E., Jenkins, D.G. & Coombes, J.S. (2008) Central hemodynamics in ultra-endurance athletes. *Journal of Science and Medicine in Sport* **11**, 390–395.

Knöpfli, B.H., Luke-Zeitoun, M., von Duvillard, S.P., Burki, A., Bachlechner, C. & Keller, H. (2007) High incidence of exercise induced bronchoconstriction in triathletes of the Swiss national team. *British Journal of Sports Medicine* **41**, 486–491.

Korkia, P.K., Tunstall-Pedoe, D.S. & Maffuli, N. (1994) An epidemiological investigation of training and injury patterns in British triathletes. *British Journal of Sports Medicine* **28**(3), 191–196.

La Gerche, A., Boyle, A., Wilson, A.M. & Prior, D.L. (2004) No evidence of sustained myocardial injury following an Ironman distance triathlon. *International Journal of Sports Medicine* Jan, **25**(1), 45–9.

Levy, C.M., Kolin, E. & Berson, B.L. (1986a) Cited in Murphy (1987) Cross training: risk or benefit? An evaluation of injuries in four athlete populations. *Sports Medicine Clinical Forum* **3**(1), 1–8.

Levy, C.M., Kolin, E. & Berson, B.L. (1986b) Cited in Murphy (1987) The effect of cross training on injury incidence, duration and severity (part 2). *Sports Medicine Clinical Forum* **3**(2), 1–8.

Lopez, A.A. & Chateau, P. (1997). Troubles digestifs en triathlon: nature et prévention. *Le Spécialiste de Médicine du Sport* **10**, 35.

Manninen, I.S.O. & Kallinen, M. (1996) Low back pain and other overuse injuries in a group of Japanese triathletes. *British Journal of Sports Medicine* **30**(2), 134–139.

Massimino F.A., Armstrong, M.A., O'Toole, M., Hillier, W.D. & Laird, R.H. (1988) Common triathlon injuries: special considerations for multisport training. *Annals of Sports Medicine* **4**, 82–86.

Meeuwisse, W.H., Tyreman, H., Hagel, B. & Emery, C. (2007) A dynamic model of etiology in sport injury: the recursive nature of risk and causation. *Clinical Journal of Sports Medicine* **17**(3), 215–219.

Migliorini, S. (1991) An epidemiological study of overuse injuries in Italian national triathletes in the period 1987–1990. *Journal of Sports Traumatology and Related Research* **13**, 197–206.

Migliorini, S. (2000) The triathlon: acute and overuse injuries. *Journal of Sports Traumatology and Related Research* **22**(4), 186–195.

Miller, T.K. (2001) Medical care at triathlons. Presented at the British Association of Sports and Exercise Medicine Meeting, Cardiff, Wales, October 2001.

Millet, G.P., Vleck, V.E. & Bentley, D.J. (2009). Physiological differences between cycling and running: lessons from triathletes. *Sports Medicine* **39(3),** 179–206.

Mitchell, S.M. (2002). Drowning probable cause of death of Ironman athlete. URL http://nn.buy.edu/print/story.cfm/39076 [accessed on July 30, 2008]

Moehrle, M. (2001) Ultraviolet exposure in Ironman triathlon. *Medicine and Science in Sports and Exercise* **33**, 1385–1396.

Mollica, M. (1998) Chronic exertional compartment syndrome of the foot: a case report. *Journal of the American Podiatric Medical Association* **88**, 21–24.

Mountjoy, M., Armstrong, N., Bizzini, L., Blimkie, C., Evans, J., Gerrard, D., Hangen, J., Knoll, K., Micheli, L., Sangenis, P. & Van Mechelen, W (2008). IOC Consensus statement on training the elite child athlete. *Clinical Journal of Sports Medicine* **18,** 122–123.

Műhlbauer, R., Lukasz, S., Faber, S., Stammberger, T. & Eckstein, F. (2000) Comparison of knee joint cartilage thickness in triathletes and physically inactive volunteers based on magnetic resonance imaging and three dimensional analysis. *American Journal of Sports Medicine* **28**(4), 541–546.

Murphy, P. (1986) Ultrasports are in—in spite of injuries. *Physician and Sportsmedicine* **14**(1), 180–189.

Murphy, P. (1987) Cross training may not reduce injury rate. *Physician and Sportsmedicine* **15**(1), 49–50.

O'Toole, M.L., Hillier, D.B., Smith, R.A. & Sisk, T.D. (1989) Overuse injuries in ultraendurance triathletes. *American Journal of Sports Medicine* **17**(4), 514–518.

O'Toole, M.L., Massimino, F.A., Hillier, D.B. & Laird, R.H. (1987) Medical considerations in triathletes: the 1984 Hawaiian Ironman Triathlon. *Annals of Sports Medicine* **3**, 121–123.

O'Toole, M.L., Miller, T.K. & Hiller, W.D.B. (2001) Triathlon. In: *Sports Injuries* (Fu, F.H. & Stone, D.A., eds.), Lippincott Williams & Wilkins, Philadelphia, pp. 778–790.

Richter, S., Betz, C. & Geiger, H. (2007) Schwere hyponatriämie mit lungen- und hirnödem bei einer Ironman-Triatletin [Severe hyponatremia, pulmonary and cerebral edema in an Ironman triathlete]. *Deutsche Medizinsche Wochenschrift* **132**, 1829–1832.

Robinson, D. & King, J. (2007). Triathlon Australia medical and safety guidelines for event coverage. URL http://www.triathlon.org.au/documents/1/4/Medical%20%20Safety%20%Guidelines%20-20%%202007.pdf [accessed on August 4, 2008]

Scott, W.A. (2004) Ironman triathlon case history. *Current Sports Medicine Reports* **3**, 163–164.

Sharwood, K.A., Collins, M., Goedecke, J.H., Wilson, G. & Noakes, T.D. (2004). Weight changes, medical complications, and performance during an Ironman triathlon. *British Journal of Sports Medicine* 38, 718–724.

Shaw, T., Howat, P., Trainor, M. & Maycock, B. (2004) Training patterns and sports injuries in triathletes. *Journal of Science and Medicine in Sport* **7**(4), 446–450.

Shellock, F.G., Hiller, W.D.B., Ainge, G.R., Brown, D.W. & Dierenfield, L. (2003) Knees of Ironman triathletes: magnetic resonance imaging assessment of older (>35 years old) competitors. *Journal of Magnetic Resonance Imaging* **17**, 122–130.

Speedy, D., Rogers, I.R., Noakes, T.D., Thompson, J.M.D., Guirey, J., Safih, S. & Boswell, D.R. (2000a) Diagnosis and prevention of hyponatremia at an ultradistance triathlon. *Clinical Journal of Sports Medicine* **10**, 52–58.

Speedy, D.B., Abraham, P., Graham, K.J. & Charlesworth, P. (2000b) External iliac artery endofibrosis in a triathlete. *Clinical Journal of Sports Medicine* **10**, 148–149.

Tennant, J. (2007). UNC triathlete health and fitness survey study. Presented at the University of North Carolina Department of Orthopaedics, 2007.

Troy, K., Hoch, A.Z. & Stavrakos, J.E. (2006). Awareness and comfort in treating the female athlete triad: are we failing our athletes? *Wisconsin Medical Journal* **105**, 21–24.

Tulloh, L., Robinson, D., Patel, A., Ware, A., Prendergast, C., Sullivan, D. & Pressley, L. (2006) Raised troponin T and echocardiographic abnormalities after prolonged strenuous exercise—the Australian Ironman triathlon. *British Journal of Sports Medicine* **40**(7), 605–9.

Villavicencio, A.T., Burneikiene, S., Hernendez, T.D. & Thramann, J. (2006) Back and neck pain in triathletes. *Neurosurgical Focus* **21**(4).

Vleck, V.E. (2003) Triathlete training and injury analysis. Ph.D. thesis. Staffordshire University, UK.

Vleck, V.E. & Garbutt, G. (1998) Injury and training characteristics of male elite, development squad and club triathletes. *International Journal of Sports Medicine* **19**(1), 38–42.

Vleck, V.E., Bentley, D.B., Grubb, H.J., & Cochrane, T.C. (2002) Training, injury and illness in National Squad triathletes: a prospective study. *Presented at the 7th Annual Congress of the European College of Sports Sciences.* Athens, Greece, July 24–28, 2002.

Vleck, V., Bentley, D. & Cochrane, T. (2003) Training in triathletes. *Science et Motricité* **50,** 33–53.

Vleck, V.E. & Bentley, D.J. (2007) Injury, illness and performance decrement in British National Squad triathletes: a prospective study. *Presented at the XIIth Annual Congress of the European College of Sports Sciences.* 19–23 July Jyväskylä, Finland, 2007.

Vleck, V.E., Bentley, D.J. & Cochrane, T. (2007a) Overuse injury incidence and risk factors in elite Olympic distance triathletes: a prospective study. *Proceedings of the VIIth Australian Conference of Science and Medicine in Sport, incorporating the Vth National Sports Injury Prevention Conference. "Be Active '07."* October 13–16, 2007, Adelaide, Australia.

Vleck, V.E., Bentley, D.J. & Cochrane, T. (2007b) Overuse injury incidence, severity and risk factors in British National Squad triathletes: a retrospective gender comparison. *Presented at the VIIth Australian Conference of Science and Medicine in Sport, incorporating the Vth National Sports Injury Prevention Conference. "Be Active '07."* October 13–16, 2007. Adelaide, Australia.

Vleck, V.E., Bentley, D.J., Millet, G.P., Bürgi, A. (2008) Pacing during an elite Olympic distance triathlon: comparison between male and female competitors. *Journal of Science and Medicine in Sport* **11**(4), 424–432.

Vleck, V.E., Bentley, D.J., Millet, G.P. & Cochrane, T. (in press). Triathlon event distance specialisation: training and injury effects. *Journal of Strength and Conditioning Research.*

Wharam, P.C., Speedy, D.L., Noakes, T.D., Thompson, J.M.D., Reid, S.A. & Holtzhausen, L (2006). NSAID use increases the risk of developing hyponatremia during an Ironman Triathlon. *Medicine and Science in Sports and Exercise* **38**(4), 618–622.

Wilk, B.R., Fisher, K.L. & Gutierrez, W. (2000) Defective running shoes as a contributing factor in plantar fasciitis in a triathlete. *Journal of Orthopaedic and Sports Physical Therapy* **30**(1), 21–31.

Wilk, B.R., Fisher, K.L. & Rangelli, D. (1995) The incidence of musculoskeletal injuries in an amateur triathlete racing club. *Journal of Orthopaedic and Sports Physical Therapy* **22**(3), 108–112.

Williams, M., Hawley, J.A., Black, R., Freke, M. & Simms, K. (1988) Injuries amongst competitive triathletes. *New Zealand Journal of Sports Medicine* **March,** 2–6.

Chapter 23

Volleyball

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Introduction

Volleyball was "invented" in 1895 in Holyoke, Massachusetts, by William G. Morgan. The game took some of its characteristics from tennis and handball, and was originally called Mintonette. Mintonette was an answer to the popularity of the rougher game of basketball, and was specifically designed for older members of the YMCA. After Alfred Halstead noticed the volleying nature of the game at its first exhibition match in 1896, the game quickly became known as volleyball and spread around the country to other YMCA locations. In 1919, about 16,000 volleyballs were distributed to American troops and allies, which sparked the growth of volleyball in new countries.

Beach volleyball started in the 1920s in Santa Monica, California. A decade later, beach volleyball began to appear in Europe. Even though beach volleyball shows many inherent similarities with indoor volleyball, the game of beach volleyball requires different skills. Therefore, elite indoor volleyball players may not necessarily compete at the same level of beach volleyball, and vice versa. In addition, the injury pattern of beach volleyball differs from that of indoor volleyball.

Indoor volleyball was introduced at the Paris Summer Olympics in 1924, where volleyball was played as part of an American sports demonstration event. Indoor volleyball was considered for official inclusion after the foundation of the Fédération Internationale de Volleyball (FIVB) in 1947. In 1964 the sport was officially included in the Olympic program. The number of teams involved in the Olympic tournament has grown steadily since 1964. Since 1996, both men's and women's events count 12 participant nations. Each of the five continental volleyball confederations has at least one affiliated national federation involved in the Olympic Games. Beach volleyball was an exhibition sport at the Barcelona Olympics in 1992. It became an official Olympic event in 1996.

Volleyball is now one of the most popular sports in the world. It is played by approximately 200 million players worldwide (FIVB 1994). Since volleyball is a noncontact game, in which players on opposing teams are separated by a net, it may be expected that the incidence of injuries is low. Nevertheless, volleyball is a sport involving rapid and forceful movements of the body as a whole, both horizontally and vertically, and because of the large forces involved in such movements it is inevitable that injuries occur (Watkins & Green 1992). De Loës (1995), for instance, found in a 3-year prospective study that with an injury incidence of 3.0 per 1,000 hours, volleyball is the eighth most injury-prone sport in the age group 14 to 20 years.

Study Limitations

There is a great difference in the methods used between the studies retrieved. Foremost, among studies various injury definitions are being used, hampering a clean comparison of injury rates

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between studies. Injuries are also reported in various ways, including per 1,000 hours of exposure, per 100 athlete-exposures (AEs), and as a percentage of the studied population. Finally, the differences in study design and study setting are an important factor contributing to differences found between studies. Where possible, this chapter will take such methodologic issues into account.

Who Is Affected by Injury?

Overall Injury Rates

Prospective and retrospective studies reporting on the incidence of injuries in men's and women's volleyball are summarized in Table 23.1. The table shows that various studies on volleyball injuries provide different levels of information, and all but two studies report the number injuries per 1,000 hours of exposure. Only two prospective studies report overall injury incidence (Bahr & Bahr 1997; Verhagen et al. 2004a). These injury numbers are comparable to the retrospective studies that have been conducted, considering that a retrospective study design generally results in a strong overestimation of the true injury risk. Such an overestimation might be shown in the incidence reported by Aagaard and Jorgenson (1996)—that is, 3.8 injuries per 1,000 hours of exposure. However, it should also be noted that this specific retrospective study

Table 23.1 Comparison of overall injury rates reported in epidemiologic volleyball-specific cohort studies.

Study	Study Design	Follow-up	Age, yr (SD)	Level of Play	Study Population			Injuries		
					Sex	No of Players	No. of Teams	Absolute No.	Percent of Total Population	Per 1,000 hr of Exposure
Verhagen et al. (2004a)	P	1 season	M, 25.2 (5.8)	High-level amateur	M + F	419	44	100	23.9	2.6
			F, 23.8 (5.7)		M	158	16	44	27.8	3.0
					F	261	28	56	21.5	2.4
Bahr & Bahr (1997)	P	1 season	M, 23.1 (4.2)	Amateur	M + F	233	26	89	38.2	1.7
			F, 21.7 (4.4)		M	112	13	—	—	1.7
					F	121	13	—	—	1.7
Augustsson et al. (2006)	R	1 season	M, 25 (4)	Elite	M + F	158	19	121	76.6	—
			F, 24 (4)		M	74	10	—	68.0	—
					F	83	9	—	77.0	—
Watkins & Green (1992)	R	1 season	27.7 (4.9)	Elite	M	86	—	46	53.0	—
Aagaard & Jorgenson (1996)	R	1 season	M, 25.0	Elite	M	67	—	98	—	3.8
			F, 24.9		F	70	—	79	—	3.8
Bahr & Reeser (2003) (beach volleyball)	R	2 mo	—	World Class	M + F	178	—	54	30.3	—
					M	92				
					F	86	—	—	—	—
							—	—		—

F = female; M = male; P = prospective; R = retrospective; SD = standard deviation.

reported on all injuries sustained, and did not make a distinction between first and overuse injuries.

Taking all studies into consideration, it is safe to state that the overall injury incidence in volleyball lies somewhere around two injuries per 1,000 hours of exposure.

Injury Rates by Playing Level

Little is known about the differences in injury rates between various playing levels. Although all descriptive studies give full information on the population that was studied, it remains difficult to ascertain how the playing levels differ between the settings in which the studies were carried out. For example, the study of Verhagen et al. (2004a) was carried out in the second and third Dutch national divisions, which is regarded as an amateur competition. In contrast, Augustsson et al. (2006) and Watkins and Green (1992) studied elite national league players in Sweden and Scotland, respectively. There seems to be a clear difference between levels in these studies. However, the elite level in the Netherlands is higher than the elite levels in Sweden and Scotland. It could well be that the second and third divisions used by Verhagen et al. (2004a) are comparable to the elite levels in Scotland and Sweden. In the same line of reasoning, the elite level in Scotland is not necessarily comparable to the elite level in Sweden.

In general, it can be said that relative differences between playing levels mentioned in the literature remain unknown. The study by Agel et al. (2007), however, does give some insight on this matter. They reported injury rates for the top three divisions in women's college volleyball. Although a trend was shown toward a somewhat lower injury rate in the lower division, this finding was not statistically significant.

Playing level may also be defined by the age of the players. Powell and Barber-Foss (1999) report on the injury patterns in high-school sports, including girls' volleyball. Although no specific age range is mentioned, it is clear that the data represent a younger age group. In girls' volleyball, an injury rate of 14.9%, equaling 1.7 injuries per 1,000 AEs was reported. The injury rate seems to be lower than what has been reported by the prospective adult studies by Bahr & Bahr (1997) and Verhagen et al. (2004a). Unfortunately, the results of Powell and Barber-Foss were not expressed per 1,000 hours of exposure. Thereby, these results can only be properly compared to the study by Agel et al. (2007), who report on women's college volleyball. The college level follows the high-school level in terms of age. The injury rates per 1,000 AEs appear to be considerably higher in college volleyball (practice = 3.3; game = 4.0) as compared with high-school volleyball (practice = 2.8; game = 1.2).

Trends in Injury Rates

From the National Collegiate Athletic Association Injury Surveillance System (NCAA ISS) in the United States, trend data on volleyball injury rates, expressed per 1,000 AEs can be extracted (Agel et al. 2007). These data, prospectively gathered from 1988 on, are limited by the fact that up until the 2004–2005 season the ISS tracked only women's volleyball. These ISS data show a gradual nonsignificant decrease in injury rates for games (6.7 per 1,000 AEs in 1988–1989; 4.0 per 1,000 AEs in 2003–2004) as well as practice (4.9 per 1,000 AEs in 1988–1989; 3.3 per 1,000 AEs in 2003–2004). Although no differences in injury rates between sexes have been reported in other epidemiologic studies, it is relatively safe to assume that a similar trend exists for men's volleyball.

Injury and Playing Position

The highest percent of injuries are sustained in the net zone. Schafle et al. (1990) reported that about 70% of all injuries were sustained in the net zone. More specifically, the attackers are at highest risk of injury (Bahr & Bahr 1997; Verhagen et al. 2004a). Especially ankle sprains, patellar tendinopathies, and shoulder pain are commonly reported problems in attackers. As discussed later in this chapter, these three injury types are overall the most common in volleyball, and especially attacking players are disposed to all risk factors for these injuries.

Where Does Injury Occur?

Anatomical Location

As can be seen in Table 23.2, the percent distribution of injuries across anatomical locations differs

Table 23.2 Distribution of injuries by anatomical location as found in various epidemiologic studies.

	Ankle	Knee	Thigh/Groin	Other Lower Extremity	Back	Shoulder	Finger	Other Upper Extremity	Other
All injuries									
Verhagen et al. (2004a)	41	12	–	21	10	9	–	7	–
Augustsson et al. (2006)	31	17	2	11	16	12	8	1	2
Watkins & Green (1992)	26	30	–	2	17	2	22	0	–
Aagaard & Jorgenson (1996)[a]	16	19	–	6	10	24	22	–	4
Bahr & Reeser (2003)[b,c]	9	23	8	9	24	14	5	3	5
Bahr & Reeser (2003)[b,d,e]	7	17	17	7	22	12	7	9	9
Agel et al. (2007)[f]	35	15	0	18	8	10	3	0	8
Agel et al. (2007)[f,g]	46	19	0	7	5	10	6	1	4
Agel et al. (2007)[f,h]	29	13	0	23	10	12	2	0	10
Acute injuries									
Verhagen et al. (2004a)	53	6	–	24	6	1	–	9	–
Bahr & Bahr (1997)[a]	54	8	4	–	11	8	7	–	8
Junge et al. (2006)[a,e]	60	20	0	0	0	20	0	0	0
Schafle et al. (1990)[a,e]	18	12	7	15	23	3	10	12	–
Bahr & Reeser (2003)[b,c]	19	17	13	9	11	4	13	6	5
Bahr & Reeser (2003)[b,d,e]	16	12	4	8	24	12	8	0	16
Overuse injuries									
Verhagen et al. (2004a)	0	20	–	16	32	32	–	0	–
Bahr & Reeser (2003)[b,c]	3	27	4	6	33	24	0	1	4
Bahr & Reeser (2003)[b,d,e]	0	21	12	6	21	12	6	3	18

[a]Injury rates shown are based on estimations derived from the original publication.
[b]Injury rates represent injuries in beach volleyball.
[c]Injury rates derived from the retrospective part of the study.
[d]Injury rates derived from the prospective part of the study.
[e]Injury rates were registered during a tournament only.
[f]Injury rates presented contain only injuries resulting in ≥10 days of time lost from activity.
[g]Injury rates represent game injuries only.
[h]Injury rates represent practice injuries only.

greatly between studies. This is mainly due to the method of injury registration and the injury definition that has been used. In addition, a number of studies have been carried out during tournaments, which reflect only a snapshot of the true injury distribution. Nevertheless, a consistent finding across studies is that overall (i.e., taking both acute and overuse injuries into consideration) the ankle is the most commonly affected body part in indoor volleyball. Descriptive studies report ankle sprains to make up 16% (Aagaard & Jorgenson 1996) to 41% (Verhagen et al. 2004a) of all volleyball injuries. Another consistent finding is that knee injuries form a large part of all volleyball-related injuries, ranging from 12% (Verhagen et al. 2004a) to 30% (Watkins & Green 1992). Between studies, there is more discrepancy regarding the magnitude of back, shoulder, and finger injuries. When looking at acute injuries alone, the ankle forms about half of all acute volleyball injuries. The back, shoulder, and knee form most of all overuse injuries.

Environmental Location

Practice versus Competition

As with all sports, in volleyball the risk for injury is higher during competition than during practice (Table 23.3). However, the absolute number of injuries is significantly higher during practice because players spend more time in practice. In volleyball, the

Table 23.3 Comparison of match (Ma) and practice (P) injury rates reported in epidemiologic volleyball-specific cohort studies.

Study	Study Design	Follow-up	Age, yr (SD)	Level of Play	Setting	Study population			Injuries		
						Sex	# players	# teams	absolute #	% of total population	per 1,000 hours of exposure
Verhagen et al. (2004a)	P	1 season	M, 25.2 (5.8)	High-level amateur	Ma	M + F	419	44	42	10.0	4.1
			F, 23.8 (5.7)		Pr	M + F	419	44	55	13.1	1.8
					Ma	M	158	16	15	9.5	3.8
					Pr	M	158	16	28	17.7	2.3
					Ma	F	261	28	27	10.3	4.2
					Pr	F	261	28	27	10.3	1.5
Bahr & Bahr (1997)	P	1 season	M, 23.1 (4.2)	Amateur	Ma	M + F	233	26	–	–	3.5
			F, 21.7 (4.4)		Pr	M + F	233	26	–	–	1.5
					Ma	M	112	13	–	–	3.9
					Pr	M	112	13	–	–	1.5
					Ma	F	121	13	–	–	3.0
					Pr	F	121	13	–	–	1.6
Schafle et al. (1990)	P	Tournament	–	Amateur	Ma	M + F	1520	–	154	10.1	19.7
					Ma	M	865	–	–	–	18.1
					Ma	F	655	–	–	–	21.7
Aagaard & Jorgenson (1996)	R	1 season	M, 25.0	Elite	Ma	M	67	–	–	–	5.8
			F, 24.9		Pr	M	67	–	–	–	3.5
					Ma	F	70	–	–	–	2.9
					Pr	F	70	–	–	–	3.9
Bahr & Reeser (2003) (beach volleyball)	R	2 mo	–	World class	Ma	M + F	178	–	–	–	3.1
					Pr	M + F	178	–	–	–	0.7
					Ma	M	92	–	–	–	2.9
					Pr	M	92	–	–	–	0.8
					Ma	F	86	–	–	–	3.3
					Pr	F	86	–	–	–	0.7
	P	Tournament			Ma	M + F	178	–	4	2.2	2.5
					Ma	M	92	–	4	4.3	3.8
					Ma	F	86	–	0	–	–

F = female; M = male; Ma = match; P = prospective; Pr = practice; R = retrospective.; SD = standard deviation injury rates reported for practice range from 1.5 injuries per 1,000 hours of exposure (Bahr & Bahr 1997) to 1.8 injuries per 1,000 hours of exposure (Verhagen et al. 2004a). Injury rates during competition are higher and more diverse between studies, ranging from 3.5 injuries per 1,000 hours of exposure (Bahr & Bahr 1997) to 19.7 injuries per 1,000 hours of exposure (Schafle et al. 1990). However, it should be said that the rates reported by Schafle et al. were derived from a single tournament, whereas other rates stem from regular matches during a volleyball season. It is reasonable to assume that this difference in setting makes a difference in the reported injury rates.

Table 23.2 provides some insight in the anatomical location of injuries sustained in practice or competition. The study by Agel et al. (2007) distinguished between injuries sustained during games and practice. Again the ankle (35% overall, 46% games, 29% practice) was the most commonly injured body part, followed by the knee (15% overall, 19% games, 13% practice) and shoulder (10% overall, 10% games, 10% practice). Subtle differences were found to exist between games and practice. Ankle injuries were more common during games than in practice, as were knee injuries. Back injuries seemed to be more common during practice than during games. In addition, a greater number of general injuries to the lower extremities were found during practice. Likely, the injuries that were reported during practice include a higher proportion of overuse injuries, as opposed to more acute injuries being reported during games. Unfortunately, a distinction between overuse and acute injuries could not be made in this study.

Indoor versus Beach Volleyball

Bahr & Reeser (2003) reported on beach volleyball injuries in a mixed retrospective and prospective study. Injuries were retrospectively registered for the 2 months preceding the World Championships in 2001, while injuries during the 2001 World Championship were prospectively registered. The injury incidence during practice (0.7 injury per 1,000 hours of exposure) was lower than the injury incidences reported for practice in indoor volleyball. In contrast, the injury incidence during matches seemed comparable to indoor volleyball (3.1 injuries per 1,000 hours of exposure). As for the prospective part of this study, an injury incidence of 2.5 injuries per 1,000 hours of match play was found. This injury rate is considerably lower than that found for indoor volleyball, but one should bear in mind that this study provides only a snapshot of the injuries during the world championship. In both parts of the study, the knee and back were the most commonly injured body parts, followed by the shoulder. Evidently, ankle injuries are not as common in beach volleyball as they are in indoor volleyball.

Aagaard et al. 1997, Scavenius & Jorgenson (1997) compared indoor and beach volleyball in a retrospective study. Similar injury rates were reported between indoor volleyball (4.2 injuries per player per 1,000 hours of exposure) and beach volleyball (4.9 injuries per player per 1,000 hours of exposure). A significantly lower percentage of ankle injuries (4% beach vs. 22% indoor) and a significantly higher percentage of shoulder injuries (42% beach vs. 16% indoor) were also reported. These differences are most likely due to the surface on which the game is being played (hard court vs. sand) and the number of players on the field (6 vs. 2). However, care should be taken in interpreting these results. In this study, most players who reported playing beach volleyball did so in the off-season, and indoor volleyball seemed to be their main sport.

Based on these two studies it is difficult to come to a solid conclusion on the comparability between indoor and beach volleyball. However, the shallow evidence points to a comparable overall injury risk between the two types of volleyball, but to different anatomical locations of injury.

When Does Injury Occur?

Injury Onset

What can be derived from descriptive studies is that overuse injuries account for about 25% of all injuries in volleyball (Verhagen et al. 2004a). Tendinopathies are the most commonly encountered types of overuse injuries, especially in the shoulder (Wang & Cochrane 2001) and knee (Ferretti et al. 1983, 1992; Ferretti 1986; Verhagen et al. 2004a). Nevertheless, it should be noted that it is difficult to register overuse injuries in population-based epidemiologic studies. Injury registration is heavily reliant on self-reporting of injuries, usually by defining an injury as any event that results in time loss from sports. Overuse injuries may be painful, require treatment, and can be considered to be an injury. However, these injuries do not always lead to time loss from sports, and are, therefore, not always reported. It is safe to state that the actual incidence and prevalence of overuse injuries is higher than what is being reported in the volleyball-specific epidemiologic literature. For example, the cross-sectional study of Lian et al. 2005, Engebretsen, and Bahr (2005) reported a 44.6% prevalence of jumper's knee as compared with the approximated 20% reported in the prospective study by Verhagen et al. (2004a).

Chronometry

Agel et al. (2007) report injury rates to be highest during preseason for practice-related injuries and highest during in-season for game-related injuries. This is in line with the overall intensity of each activity during the regular course of a volleyball season. Unfortunately, there are no data on differences in injury rates during the competitive season. It could well be that injury rates change during the course of competition due, for instance, to fatigue (overall increase in injury rate), conditioning (overall decrease in injury rate), or seasonal influences (steep incline in injury rate during the winter).

What Is the Outcome?

Injury Type

The number of studies that provide a complete overview of injury types is limited. A few case studies exist, but these report on a single specific injury and do not provide any data on the occurrence of that injury type in volleyball. In addition, such case-like studies tend to report on the more rare injuries—for example, scytalidium keratitis (Farjo et al. 2006), humerus fracture (Hakozaki et al. 2006), vascular complications (Arko t al. 2001, Cook et al. 2004), suprascapular neuropathy (Dramis & Pimpalnerkar 2005), isolated electrothermal capsulorrhaphy (Enad et al. 2004), spontaneous pneumomediastinum (Mihos et al. 2004), and glenoid osteolysis (Spoloti 2007).

Six studies provide a general overview of injury types in volleyball (Agel et al. 2007; Solgard et al. 1995; Schafle et al., 1990). These studies have methodologic restrictions, hampering the generalizability of results to a broader setting. For instance, the study of Schafle et al. (1990) was on volleyball injuries during a single tournament, and the study by Solgard et al. (1995) included only injuries in players who presented at an emergency department. Sprains are the most common injury type overall (range, 26–73%), followed by strains (range, 4–58%). Other studies show similar injury types to be dominant in volleyball. In a one-season retrospective study, Watkins and Green (1992) found ligament damage to be the most common injury (39%), followed by muscle damage (19%), tendon damage (15%), cartilage damage (6%), bone fracture (2%), and dislocation (2%). Agel et al. (2007) found that during games, sprains were commonest (52%), followed by strains (17%). During practices, strains were shown to be equally as prevalent as sprains, 35% and 34% of all injuries, respectively. Agel et al. (2007) also found ankle sprains to be the commonest specific injury type during practices as well as games: 29% (0.83 per 1,000 AEs) and 44% (1.44 per 1,000 AEs) of all injuries, respectively.

Taken together, on the basis of these studies we may conclude that volleyball athletes are at greatest risk for strains and sprains as a result of acute dynamic tissue overload.

Time Loss

There is considerable discrepancy in the reporting of time loss in the volleyball-injury literature. Verhagen et al. (2004a) report an overall mean (±SD) time loss of 4.3 ± 4.6 volleyball sessions due to injury. The reported mean absence due to acute injuries was 4.0 ± 3.8 sessions, and to overuse injuries 4.0 ± 6.2 sessions. Aagaard and Jorgenson (1996) reported an overall mean absence of 13 days in women and 10 days in men. However, for this study it is unknown whether the number of days absent are actual calendar days or volleyball sessions.

Agel et al. (2007) report on injuries resulting in at least 10 consecutive days of restricted or total loss of participation from 1988 to 2004. In women, about 19% of all practice injuries and 23% of all match injuries restricted volleyball participation for ⩾10 days. In both games and practices, both the ankle (practice 18.4%; match 29.1%) and knee (practice 14.6%; match 25.7%) accounted for the most common severe injuries.

Aagaard and Jorgenson (1996) reported a different time loss for specific injuries. For both men (21 days) and women (34 days) knee injuries resulted in the longest time loss. Women seemed to have more severe shoulder injuries, with a mean time loss of 13 days (vs. 3 days for men). Men were shown to have more severe ankle/foot injuries, with a time loss of 15 days (vs. 8 days for women). Aagaard and Jorgenson (1996) also provided information about how long injury symptoms last. Although the overall time loss was relatively low, the symptoms in both men and women persisted for a mean of 59 days, with symptoms lasting longer in men than in women.

It should be mentioned that reporting mean time loss due to injury provides an overestimation of the true time loss. This is clearly illustrated in Figure 23.1, which makes clear that time loss due to injury is skewed. A similar skewness was shown in the studies of Watkins and Green (1992), Aagaard et al. (1997), and Bahr and Reeser (2003). Watkins and Greene (1992) showed that 74% of all injuries lasted ⩽2 weeks, while 10% of all injuries resulted in an absence from volleyball for 7 to 14 weeks. This is similar to the absence reported by Aagaard et al. (1997); 80% lasted ⩽2 weeks and 7% lasted ⩾7 weeks. Bahr and Reeser (2003) have shown the time loss to be relatively mild in elite beach volleyball. From their retrospective study, they reported 23 time-loss injuries, of which only 1 lasted ⩾3 weeks and 18 <1 week.

Clinical Outcome

In women's intercollegiate volleyball, 0.3 injury per 1,000 AEs required surgery, as compared with 3.5 injuries per 1,000 AEs requiring surgery in women's gymnastics (NCAA ISS 2008). Although no men's volleyball data are in the NCAA system, other studies show similar rates of volleyball requiring treatment between sexes. For example,

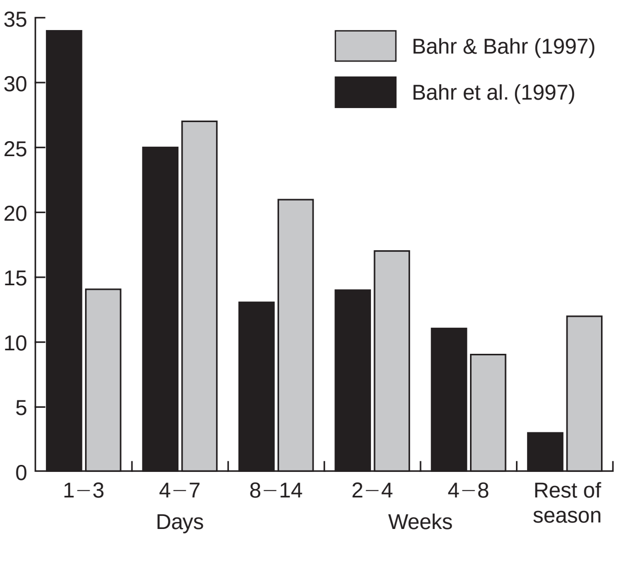

Figure 23.1 Absence from volleyball because of injury.

Aagaard and Jorgenson (1996) found that both women and men sought the same medical care. The majority of injuries (39%) were not seen by a physician or physiotherapist. Most injuries that required medical attention were treated by a physical therapist (35%), followed by treatment by a physician (17%). Only 3% of all injuries required admittance to a hospital. These results are in line with the time loss due to injury as a measure of injury severity. The majority of injuries last ≤2 weeks, and it is reasonable to assume that less severe injuries require minimal to no medical attention.

Wang and Cochrane (2001) looked specifically at shoulder injuries. They found that 24 of the 27 injured players sought some form of medical attention. The shoulder is heavily loaded when playing volleyball. Any discomfort in the shoulder will affect playing technique. For this reason, players are likely to seek medical attention for shoulder injuries more swiftly than for other injuries.

Clinical outcome of acute ankle injuries has been described in the volleyball literature. Bahr et al. (1994) reported that 95% of all acute ankle injuries were treated on-site with ice. This first aid treatment was given by teammates in 60% of the cases, by coaches in 49%, and by a doctor or physical therapist in 5%. Further treatment was carried out in only 27% of injuries, and a rehabilitation program was carried out by only 29% of all injured players. In addition, this study clearly showed that an acute ankle injury leads to an increased recurrence risk. The same conclusion was drawn by Verhagen et al. (2004a), who showed that the recurrence risk for ankle injury was doubled during the first 12 months after an initial ankle sprain.

Economic Cost

The study by Verhagen et al. (2005) is the only study reporting on the economic consequences of volleyball injuries, more specifically on the costs of ankle sprains. It was found that the mean total costs of a single ankle sprain was 360.60 ± 426.73€. The reported total cost of ankle sprains was the sum of the direct and indirect costs of ankle sprains. The direct costs consisted of all medical costs due to ankle sprains. The mean direct cost per ankle sprain was 43.50 ± 42.33€. Indirect costs were calculated based on the mean absence from work due to the injury, as registered in cost diaries. The mean indirect cost per ankle sprain was 318.10 ± 401.13€ (1€=1.40$).

What Are the Risk Factors?

Intrinsic Factors

Sex

The few studies that directly compare injury rates for men and women have found no significant differences between sexes. Although some studies report a trend toward a somewhat higher injury rate in either male players (3.0 injuries per 1,000 hours of exposure vs. 2.4 for female players; Verhagen et al. 2004a) or female players (53% vs. 43% in male players; Augustsson et al. 2006; 2.17 injuries per 100 hours of exposure vs. 1.81; Schafle et al. 1990), these findings were not significant.

Previous Ankle Injury

Across all sports, the most important risk factor for an ankle sprain injury is a history of an ankle sprain in the same ankle. Up to 80% of ankle sprains involve previously injured ankles (Reeser et al. 2006). Furthermore, as specifically shown for volleyball (Bahr & Bahr 1997; Verhagen et al. 2004a), the risk of injury is greatest within the first 6 months after the previous injury (and declines thereafter). Athletes who have sustained an ankle sprain within the past 6 to 12 months are approximately 10 times more likely to suffer a repeat injury as compared with those without a history of recent injury.

Extrinsic Factors

Hard Surfaces

Ankle sprains occur less frequently in beach volleyball than in indoor volleyball (Aagaard et al. 1997; Bahr & Reeser 2003). Although it is tempting to state that this is because of the biomechanical effects of playing in the soft sand, this may also be the result of the reduced player density in beach volleyball.

Volume of Jumping

Jumper's knee is more prevalent among sports and athletes who train on hard surfaces, and prevalence increases with the volume of jumping (Ferretti et al. 1985; Ferretti 1986). This may, in part, explain why beach volleyball athletes have a lower prevalence of symptomatic patellar tendinopathy as compared with indoor volleyball athletes (Bahr & Reeser, 2003). In addition, it is not surprising that indoor middle blockers tend to suffer more from jumper's knees than other players.

Jumping Technique

Although the data are by no means conclusive, anatomical factors do not appear to be a significant risk factor for patellar tendinopathy (Lian et al. 1996a). On the other hand, biomechanical studies have revealed an increased incidence in jumper's knee among those athletes who jump highest, and in those in whom the deepest knee flexion angle develops during landing from a spike jump (Lian et al. 1996b, 2003; Richards et al. 1996). Other studies have confirmed these factors relating to jumping technique and added other biomechanical factors that might predispose an athlete to jumper's knee (Bisseling et al. 2007, 2008). Technical considerations may therefore also be important (Reeser et al. 2006).

What Are the Inciting Events?

This section will focus specifically on ankle sprains, patellar tendinopathy (jumper's knee), and shoulder pain. These injuries are the most common injury types in volleyball, and there is an abundance of evidence describing inciting events for these injuries.

Ankle Sprains

Ankle sprains occur most frequently at the net, as the direct result of legal contact across the centerline that occurs between the attacker and the opposing blocker(s) (Bahr & Bahr 1997; Verhagen et al. 2004a) (Figure 23.2).

Studies consistently reveal that about half of all ankle sprains occur when a blocker lands on the foot of an opposing attacker who has, legally, penetrated the centerline (Bahr et al. 1994; Bahr & Bahr 1997; Verhagen et al. 2004a). It is common for the attacker to try to catch up to a set that is too low and close to the net. In such a case, the momentum and jump trajectory take the attacker under the net.

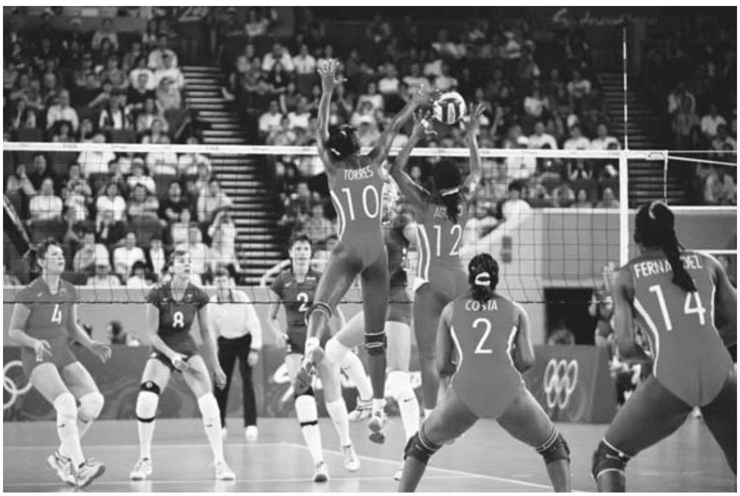

Figure 23.2 High player density at the net zone predisposes a player to risk for ankle sprains in indoor volleyball. © IOC/Steve MUNDAY.

The blocker, who for tactical reasons jumps later than the attacker, may land on the attacker's foot within this so-called conflict zone.

Approximately one fourth of ankle sprains in volleyball occur when a blocker lands on a teammate's foot when participating in a multiperson block. Consequently, middle blockers and outside attackers are at greatest risk for ankle sprain, while setters and defensive specialists have a comparatively lower risk (Reeser et al. 2006).

Patellar Tendinopathy

Patellar tendinopathy is considered an overuse injury, meaning that symptoms occur after a threshold of cumulative tissue injury has been exceeded. However, it is not well understood why, despite equivalent training loads, some athletes become symptomatic and others do not (Scott et al. 2005).

Shoulder Injury

Most research on shoulder injuries has been conducted in baseball (Fleisig et al. 1996), and relatively few studies have focused on the volleyball-specific pathology of shoulder pain (Cools et al.2005; Kugler et al. 1996; Wang et al. 2000; Wang & Cochrane 2001). By looking at general biomechanical knowledge, it can be concluded that the force imparted to the volleyball during a spike is generated in large measure by the transfer of kinetic energy from the torso through the shoulder to the distal upper limb (Reeser et al. 2006).

One of the few to accurately document on the volleyball specific events leading to shoulder overuse injuries is by Kugler et al. (1996). Repetitive spiking results in distention and laxity of the anterior capsule, as well as tightening of the posterior capsular structures. These two phenomena promote anterior translation of the humeral head during the spiking motion, through a series of events ultimately manifesting as a SICK scapula (scapular malalignment, inferior medial border prominence, coracoid tightness, scapular dyskinesis).

According to Reeser et al. (2006), an elite volleyball athlete performs more than 40,000 spikes in a season. Although the true load and kinematics of a spike are unknown, it may be clear that the immense spike volume and need for dynamic stabilization put a tremendous load on a volleyball player's shoulder. Although it may be intuitive to think that this load eventually must lead to shoulder pain, the natural history of shoulder pain in volleyball players is not well understood.

Injury Prevention

As for preventing ankle sprains, numerous intervention strategies have been proposed. It should be noted that not all of the proposed strategies have been formally tested, and that many methods are used based on best practices. This section will discuss only preventive measures that have been proven effective in a volleyball setting.

External Prophylactic Measures

Although widely used, there is almost no volleyball-specific evidence that prophylactic bracing or taping is effective for the prevention of ankle injuries. Only Pedowitz et al. (2008) investigated the effect of prophylactic bracing within volleyball. They compared ankle-injury rates within their own institution with NCAA rates, after the use of ankle braces was made obligatory for all players at their institution. They found that the ankle injury rate dropped to nearly zero within their institute (0.07 injury per 1,000 AEs). Although some methodologic side notes should be made regarding this study, these results are in line with what has been found in other sports, and do show the potential of prophylactic bracing in volleyball.

Rule Changes

Most ankle sprains occur at the net and involve (legal) penetration of the centerline. Therefore, Bahr (1996) proposed a rule change that would have made any contact with the centerline a fault. The rule was tested during a Norwegian tournament, and nearly 20-fold more centerline violations were whistled than under the existing rule. For this reason, the proposed intervention was deemed unworkable, and abandoned. Interestingly, despite a more liberal NCAA rule permitting complete penetration of the centerline as long as such penetration does not interfere with play on the opponent's side of the court, analysis of the incidence of ankle sprains reported to the NCAA ISS indicated that the incidence of ankle sprains did not increase significantly (Reeser et al. 2006). Therefore, it could be said that a rule targeting centerline penetration within the "conflict zone" might be effective in reducing the incidence of ankle sprains without adversely affecting the flow of the game, but a study has yet to be conducted.

Neuromuscular training programs

Bahr et al. 1997, Lian & Bahr (1997) showed that neuromuscular (proprioceptive) training reduces the risk of ankle injuries among volleyball players when included as part of a multifaceted intervention including technical training and injury awareness. From this study, it remains unknown what the sole effect of neuromuscular training was. Another volleyball-specific study indicated that a preventive neuromuscular training program reduced the incidence of ankle sprain injury by 50%, particularly in those with a history of ankle sprain (Verhagen et al. 2004b).

Eccentric training protocols have been proven to be an effective means of treating tendinopathies (Jonsson & Alfredson 2005; Young et al. 2005). However, the opposite has been shown as well (Visnes et al. 2005). The difference between positive and negative results is that a lack of effect was shown in a study that was carried out during a regular volleyball season. It could be that the load that is applied to the patellar tendon during a regular volleyball game is too high for a rehabilitative program to show an effect. In other words, some additional rest is needed. In addition, it is important to rehabilitate beyond the absence of symptoms and to avoid return to play before the athlete is adequately rehabilitated in order to maximize secondary prevention of recurrent injury (Reeser et al. 2006).

Technique

Bahr et al. (1997) showed that technique training as part of a multifaceted intervention program, lowered the incidence of ankle sprain significantly. The tested training program emphasized proper spike approach, take-off, and landing technique, in addition to blocking rills. However, as mentioned above, this result was derived form a multifaceted intervention program that also included balance-board training and injury awareness. Therefore, the effect of technical training alone remains unknown.

Further Research

Volleyball injuries are a relatively uncharted territory in sports medicine research. Regarding injury incidence, there are some proper descriptive epidemiologic studies specifically on volleyball showing that ankle sprains, patellar tendinopathies, and shoulder pain are injuries of interest. Nevertheless, there are some minor (but nonetheless important) gaps in our knowledge on the epidemiology of volleyball injuries. Specifically, beach volleyball is a sport that has emerged very fast and is still increasing in popularity, and yet it remains almost completely unknown in the sports medicine literature. The little evidence there is shows that the injury risk and injury profile of beach volleyball players is different to indoor volleyball. Therefore, specific studies are needed to ascertain the risks associated with this discipline, and beach volleyball should be considered a different sport when it comes to sports medicine research and injury prevention.

Only two of the volleyball studies reviewed used a prospective cohort design, while all others were either retrospective or investigated injuries only during a tournament. In order to obtain more accurate injury information, season-long prospective cohort studies are needed. A study using this design should have a particular interest in injury types, overuse injuries, sex differences, playing level, chronometry, and injury costs. These topics are rarely described in sufficient detail and by using a proper study design, and, therefore, require further investigation.

In addition, there needs to be a stronger focus on the definition of injury, reporting of injury, methods of data collection, and statistical analyses.

This chapter focused in part specifically on the three most common injuries described by the current volleyball literature: ankle sprains, patellar tendinopathy, and shoulder pain. Ankle sprains are fairly well researched. In contrast, risk factors and prevention of patellar tendinopathy and shoulder pain remain largely unknown for volleyball. To a certain extent, results from other sports can be extrapolated to volleyball, but in order to be able to develop volleyball-specific preventive measures, volleyball-specific research is needed on these injury types. When investigating risk factors and mechanisms associated with these three injury types, one should realize that the path leading to injury is multifactorial (Bahr & Krosshaug 2005). Therefore, future studies looking at the events leading to these (and other injuries) should use proper design and analyses in order to ascertain the full picture.

Ankle Sprains

Numerous intervention strategies have been proposed for preventing ankle sprains. It should be noted that not all of the proposed strategies have been formally tested, and that many methods are used based on best practices. Proposed preventive strategies include modification of the centerline rule, improving jump technique (attacker spike approach), improving the quality of rehabilitation following previous ankle sprain, and the use of external support (tape or brace) in an effort to protect the ankle from injury. Only one study has been conducted on the effectiveness of bracing for preventing volleyball-related ankle sprains (Pedowitz et al. 2008). Although the methods used are questionable, positive results were found. From other sports it is known that ankle braces and tape are effective in preventing recurrent ankle sprain (Verhagen et al. 2000, van Mechelen & de Vente 2000). However, given the specific risk factors for ankle sprains unique for volleyball, results from other sports should be extrapolated with caution. These results, as well as the high rate of use of these measures, calls for more effect studies on prophylactic bracing and taping for the prevention of ankle sprains within volleyball.

Patellar Tendinopathy

Although no volleyball-specific studies have been done, there is some evidence from other sports suggesting that the prevalence of patellar tendinopathy is sex-dependent (Lian et al. 2005). It is reasonable to assume that proper jumping and landing technique may prevent patellar tendinopathy. When an athlete manages to minimize valgus strain on the lead knee during the jump approach and minimizes knee flexion during landing, the cumulative load on the patellar tendon may be minimized. However, more research is needed to determine whether proper technique might truly prevent a jumper's knee from occurring.

Given the effect of surface and volume on jumper's knee, minimizing the volume of jump training on hard playing surfaces might be the most sensible solution (Reeser et al. 2006). It may be entirely reasonable to avoid increasing the volume of training beyond 10% per week, a somewhat uncharted golden rule to prevent overuse injuries. A great number of athletes suffering from patellar tendinopathy use patellar straps. These straps were originally designed to redistribute the forces acting on the patellar tendon, and thereby reducing the actual load on the tendon. However, there is no evidence from any sport to suggest that the use of patellar straps is truly an effective method for the treatment or preventing jumper's knee.

Shoulder Pain

The risk factors for developing shoulder pain among volleyball athletes are not thoroughly investigated in epidemiologic research. Using common sense, the leading risk factors should include a history of shoulder pain as well as the magnitude of the load to which the athlete is exposed. Specifically for beach volleyball, additional potential, intuitive, risk factors that have yet to be verified in volleyball include the effect of the environment on both the trajectory of the ball, and the weight of the ball (wet balls are heavier) (Reeser et al. 2006), core stability, an asymmetry in glenohumeral internal rotation (Burkhart et al. 2003), sex (Mjaanes & Briner 2005), and spiking style (Oka et al. 1976)

To date there are no volleyball-specific effective interventions for the prevention of shoulder pain. Using common sense, a handful of potential interventions can be established. A reduction in the training load, training volume, or both seems to be the most logical preventive measure, as it results in less tissue overload and provides greater opportunities for tissue recovery. Burkhart et al. (2003) showed a reduction in the prevalence of shoulder symptoms in tennis and baseball players by addressing the posterior capsular tightness through a consistent season-long stretching program. Based on this finding, it would also seem appropriate to make core strengthening and stability training an integral part of volleyball training. Such interventions have yet to be investigated in volleyball athletes. Athletes with shoulder pain should be instructed on spiking techniques that minimize the load on the glenohumeral joint. The problem is that it is currently unknown which techniques provide what specific load.

References

Aagaard, H. & Jørgensen, U. (1996) Injuries in elite volleyball. *Scandinavian Journal of Medicine & Science in Sports* **6**(4), 228–232.

Aagaard, H., Scavenius, M. & Jorgenson, U. (1997) An epidemiological analysis of the injury pattern in indoor and in beach volleyball. *International Journal of Sports Medicine* **18**(3), 217–221.

Agel, J., Palmieri-Smith, R.M., Dick, R., Wojtys, E.M. & Marshall, S.W. (2007) Descriptive epidemiology of collegiate women's volleyball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988–1989 through 2003–2004. *Journal of Athletic Training* **42**(2), 295–302.

Arko, F.R., Harris, E.J., Zarins, C.K. & Olcott, C. (2001) Vascular complications in high-performance athletes. *Journal of Vascular Surgery* **33**(5), 935–942.

Augustsson, S.R., Augustsson, J., Thomeé, R. & Svantesson, U. (2006) Injuries and preventive actions in elite Swedish volleyball. *Scandinavian Journal of Medicine & Science in Sports* **16**(6), 433–440.

Bahr, R. (1996) The effect of a new centerline violation rule on the quality and flow of volleyball games. *International Volleytech* **2**, 14–19.

Bahr, R. & Bahr, I.A. (1997) Incidence of acute volleyball injuries: a prospective cohort study of injury mechanisms and risk factors. *Scandinavian Journal of Medicine & Science in Sports* **7**(3), 166–171.

Bahr, R. Karlsen, R., Lian, O. & Ovrebo, R.V. (1994). Incidence and mechanisms of acute ankle inversion injuries in volleyball. *American Journal of Sports Medicine* **22**(5), 595–600.

Bahr, R. & Krosshaug, T. (2005) Understanding injury mechanisms: a key component of preventing injuries in sport. *British Journal of Sports Medicine* **39**(6), 324–329.

Bahr, R., Lian, O. & Bahr, I.A. (1997) A twofold reduction in the incidence of acute ankle sprains in volleyball after the introduction of an injury prevention program: a prospective cohort study. *Scandinavian Journal of Medicine & Science in Sports* **7**, 172–177.

Bahr, R. & Reeser, J. (2003) Injuries among world-class professional beach volleyball players: the Fédération Internationale de Volleyball beach volleyball injury study. *American Journal of Sports Medicine* **31**(1), 119–125.

Bisseling, R.W., Hof, A.T., Bredeweg, S.W., Zwerver, J. & Mulder, T. (2007). Relationship between landing strategy and patellar tendinopathy in volleyball. *British Journal of Sports Medicine* **41**, e8.

Bisseling, R.W., Hof, A.T., Bredeweg, S.W., Zwerver, J. & Mulder, T. (2008). Are the take-off and landing phase dynamics of the volleyball spike jump related to patellar tendinopathy? *British Journal of Sports Medicine* **42,** 483–489.

Burkhart, S.S., Morgan, C.D. & Kibler, W.B. (2003) The disabled throwing shoulder: spectrum of pathology, part I: pathoanatomy and biomechanics. *Arthroscopy* **19**(4), 404–420.

Cook, J.A., Feller, J.A., Bonar, S.F. & Khan, K.M. (2004) Abnormal tenocyte morphology is more prevalent than collagen disruption in asymptomatic athletes' patellar tendons. *Journal of Orthopaedic Research* **22**(2), 334–338.

Cools, A.M., Witvrouw, E.E., Mahieu, N.N. & Danneels (2005) Isokinetic scapular muscle performance in overhead athletes with and without impingement symptoms. *Journal of Athletic Training* **40**(2), 104–110.

De Loës, M. (1995) Epidemiology of sports injuries in the Swiss Organization "Youth and Sports" 1987–1989: injuries, exposures and risks of main diagnosis. *International Journal of Sports Medicine* **16**, 134–138.

Dramis, A. & Pimpalnerkar, A. (2005). Suprascapular neuropathy in volleyball players. *Acta orthopaedica Belgica* **71**(3), 269–72

Enad, J.G., ElAttrache, N.S., Tibone, J.E., Yocum, L.A. (2004). Isolated electrothermal capsulorrhaphy in overhand athletes. *Journal of shoulder and elbow surgery/American Shoulder and Elbow Surgeons* **13**(2), 133–7.

Farjo QA, Farjo RS, Farjo AA. (2006) Scytalidium keratitis: case report in a human eye. Cornea **25**(10), 1231-3.

Federation Internationale de Volleyball (FIVB). (1994). Lausanne, Switzerland. *X-Press* **47**(Jan), 1.

Ferretti, A. (1986) Epidemiology of jumper's knee. *Sports Medicine* **3**(4), 285–295.

Ferretti, A., Ippolito, E., Mariani, P. & Puddu, G. (1983) Jumper's knee.

American Journal of Sports Medicine **11**(2), 58–62.
Ferretti, A., Puddu, G., Mariani, P.P. & Neri, M. (1985) The natural history of jumper's knee: patellar or quadriceps tendonitis. *International Orthopaedics* **8**(4), 239–242.
Ferretti, A., Papandrea, A., Conteduca, F. & Mariani, P.P. (1992) Knee ligament injuries in volleyball. *American Journal of Sports Medicine* **20**(2), 203–207.
Fleisig, G.S., Barrentine, S.W., Escamilla, R.F. & Andrews, J.R. (1996) Biomechanics of overhand throwing with implications for injuries. *Sports Medicine* **21**(6), 421–437.
Hakozaki, M., Iwabuchi, M., Otani, K., Konno, S., & Kikuchi, S. (2006). Unusual fracture of the humerus in a volleyball player: a case report. *International Journal of Sports Medicine* **28**, 977–979.
Jonsson, P. & Alfredson, H. (2005) Superior results with eccentric compared to concentric quadriceps training in patients with jumper's knee: a prospective randomised study. *British Journal of Sports Medicine* **39**(11), 847–850.
Junge, A., Langevoort, G., Pipe, A., Peytavin, A., Wong, F., Mountjoy, M., Beltrami, G., Terrell, R., Holzgraefe, M., Charles, R. & Dvorak, J. (2006) Injuries in team sport tournaments during the 2004 Olympic Games. *American Journal of Sports Medicine* **34**(4), 565–576.
Kugler, A., Krüger-Franke, M., Reininger, S., Trouillier, H.H. & Rosemeyer, B. (1996) Muscular imbalance and shoulder pain in volleyball attackers. *British Journal of Sports Medicine* **30**(3), 256–259.
Lian, O., Holen, K.J., Engebretsen, L. & Bahr, R. (1996a) Relationship between symptoms of jumper's knee and the ultrasound characteristics of the patellar tendon among high level male volleyball players. *Scandinavian Journal of Medicine and Science in Sports* **6**(5), 291–296.
Lian, O., Engebretsen, L., Ovrebø, R.V. & Bahr, R. (1996b) Characteristics of the leg extensors in male volleyball players with jumper's knee. *American Journal of Sports Medicine* **24**(3), 380–385.
Lian, O., Refsnes, P., Engebretsen, L. & Bahr, R. (2003) Performance characteristics of volleyball players with patellar tendinopathy. *American Journal of Sports Medicine* **31**(3), 408–413.
Lian, O.B., Engebretsen, L. & Bahr, R. (2005) Prevalence of jumper's knee among elite athletes form different sports: a cross-sectional study. *American Journal of Sports Medicine* **33**, 561–567.
Mihos, P., Potaris, K., Gakidis, I., Mazaris, E., Sarras, E., Kontos, Z. (2004) Sports-related spontaneous pneumomediastinum. *The Annals of thoracic surgery* **78**(3), 983–6.
Mjaanes, J.M. & Briner, W.W. (2005) Trends in shoulder injuries among elite volleyball players in the USA. *British Journal of Sports Medicine* **39**, 397.
National Collegiate Athletic Association Injury Surveillance System. (2008) URL http://www.ncaa.org/wps/wcm/connect/resources/file/eb2d0049708c901/Fig7_2005.pdf?MOD=AJPERES [accessed, June 5, 2008]
Pedowitz, D.I., Reddy, S., Parekh, S.G., Huffman, G.R. & Sennet, B.J. (2008). Prophylactic bracing decreases ankle injuries in collegiate female volleyball players. *American Journal of Sports Medicine* **36**(2), 324–327.
Powell, J.W. & Barber-Foss K.D. (1999). Injury patterns in selected high-school sports: a review of the 1995–1997 seasons. *Journal of Athletic Training* **34**(3), 277–84.
Reeser, J.C., Verhagen, E., Briner, W.W., Askeland, T.I. & Bahr, R. (2006) Strategies for the prevention of volleyball related injuries. *British Journal of Sports Medicine* **40**, 594–600.
Richards, D.P., Ajemian, S.V., Wiley, J.P., & Zernicke, R.F. (1996) Knee joint dynamics predict patellar tendinitis in elite volleyball players. *American Journal of Sports Medicine* **24**(5), 676–683.
Schafle, M.D., Requa, R.K., Patton, W.L. & Garrick J.G. (1990) Injuries in the 1987 national amateur volleyball tournament. *American Journal of Sports Medicine* **18**(6), 624–631.
Scott, A., Khan, K.M., Heer, J., Cook, J.L., Lian, O. & Duronio, V. (2005) High strain mechanical loading rapidly induces tendon apoptosis: an ex vivo rat tibialis anterior model. *British Journal of Sports Medicine* **39**(5), e25.
Solgard, L., Nielsen, A.B., Moller-Madsen, B., Jacobsen, B.W., Yde, J. & Jensen, J. (1995) Volleyball injuries presenting in casualty: a prospective study. *British Journal of Sports Medicine* **29**(3), 200–204.
Spoliti, M. (2007) Glenoid osteolysis after arthroscopic labrum repair with a bioabsorbable suture anchor. *Acta orthopaedica Belgica* **73**(1), 107–10.
van Mechelen, W., Hlobil, H. & Kemper, H.C.G. (1992) Incidence, severity, aetiology and prevention of sports injuries: a review of concepts. *Sports Medicine* **14**(2), 82–99.
Verhagen, E., van Mechelen, W. & de Vente, W. (2000) The effect of preventive measures on the incidence of ankle sprains.*Clinical Journal of Sports Medicine* **10**(4), 291–296.
Verhagen, E., van der Beek, A., Bouter, L., Bahr, R. & van Mechelen, W. (2004a) A one season prospective cohort study of volleyball injuries. *British Journal of Sports Medicine* **38**(4), 477–481.
Verhagen, E., van der Beek, A., Twisk, J., Bouter, L., Bahr, R. & van Mechelen, W. (2004b) The effect of a proprioceptive balance board training program for the prevention of ankle sprains: a prospective controlled trial. *American Journal of Sports Medicine* **32**(6), 1385–1393.
Verhagen, E., van Tulder, M., van der Beek, A., Bouter, L. & van Mechelen, W. (2005) An economic evaluation of a proprioceptive balance board training programme for the prevention of ankle sprains in volleyball. *British Journal of Sports Medicine* **39**(2), 111–115.
Visnes, H., Hoksrud, A., Cook, J. & Bahr, R. (2005) No effect of eccentric training on jumper's knee in volleyball players during the competitive season: a randomized clinical trial. *Clinical Journal of Sports Medicine* **15**(4), 227–234.
Wang, H.K. & Cochrane, T. (2001) A descriptive epidemiological study of shoulder injury in top level English male volleyball players. *International Journal of Sports Medicine* **22**, 159–163.
Wang, H.K., Macfarlane, A. & Cochrane, T. (2000) Isokinetic performance and shoulder mobility in elite volleyball athletes from the United Kingdom. *British Journal of Sports Medicine* **34**(1), 39–43.
Watkins, J. & Green, B.N. (1992) Volleyball injuries: a survey of injuries of Scottish National League male players. *British Journal of Sports Medicine* **26**(2), 135–137.
Young, M.A., Cook, J.L., Purdam, C.R., Kiss, Z.S. & Alfredson, H. (2005) Eccentric decline squat protocol offers superior results at 12 months compared with traditional eccentric protocol for patellar tendinopathy in volleyball players. *British Journal of Sports Medicine* **39**(2), 102–105.

Chapter 24

Weightlifting

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Introduction

Weight training is a popular recreational activity that is performed by people from all walks of life in many parts of the world. While most of these individuals use weight training as just one part of their health-and-fitness routine, a number of athletes compete in sports in which weight training is the primary form of training, it is the competitive event, or both. These sports include weightlifting, powerlifting, bodybuilding, and strongman.

Weightlifting currently requires the lifter to lift the maximum load for one repetition in two exercises; the clean and jerk and the snatch. In the snatch, weightlifters lift the bar to arm's length above the head in one movement. In the clean and jerk, they lift the bar to the shoulders, stand up straight, then jerk the bar to arm's length above the head (Figure 24.1). Lifters are allowed three attempts at each lift, and their best snatch and best clean-and-jerk figures are added to determine the winner. As both of these exercises require the barbell to be lifted explosively from the floor to an overhead position, they produce probably the greatest power outputs of any human activity (Garhammer 1993). Men's weightlifting was on the program of the first modern Olympic Games in Athens in 1896. Women participated for the first time at the Olympic Games in Sydney in 2000.

Powerlifting is similar to weightlifting in that the lifters attempt to lift the maximum load for one repetition. However, in powerlifting competitions the three lifts are the squat, bench press, and deadlift. Strongman competitions in some ways are the most similar form of weight training competition to that done in ancient times, during which events included stone lifting, log press, farmers' walks, tire flipping, and truck pulling. While some of these events are similar to weightlifting and powerlifting, with the athletes attempting to lift the heaviest load for one repetition, many of the events are timed, with the winner being the fastest athlete to complete the task. Bodybuilding differs from the other three weight-training sports in that it is not judged on the weight lifted in competition but rather on the physical appearance of the athlete. Specifically, the competitors are judged on muscle bulk, balance between muscle groups (symmetry), muscular density, and definition. Although these four sports all have annual world championship events for male and female athletes of various bodyweight classes, weightlifting is currently the only one of these sports with Olympic status.

Because of the heavy loads that can be lifted in these sports and the positions and postures that these athletes need to adopt in training and competition, the joint moments (torques) as well as shear and compressive forces produced during these types of exercises can be very large (Cholewicki et al. 1991; Escamilla et al. 1998, 2000, 2001a). Thus, some members of the public, sporting, medical, and scientific communities may believe that these activities are inherently dangerous and that athletes who regularly perform these

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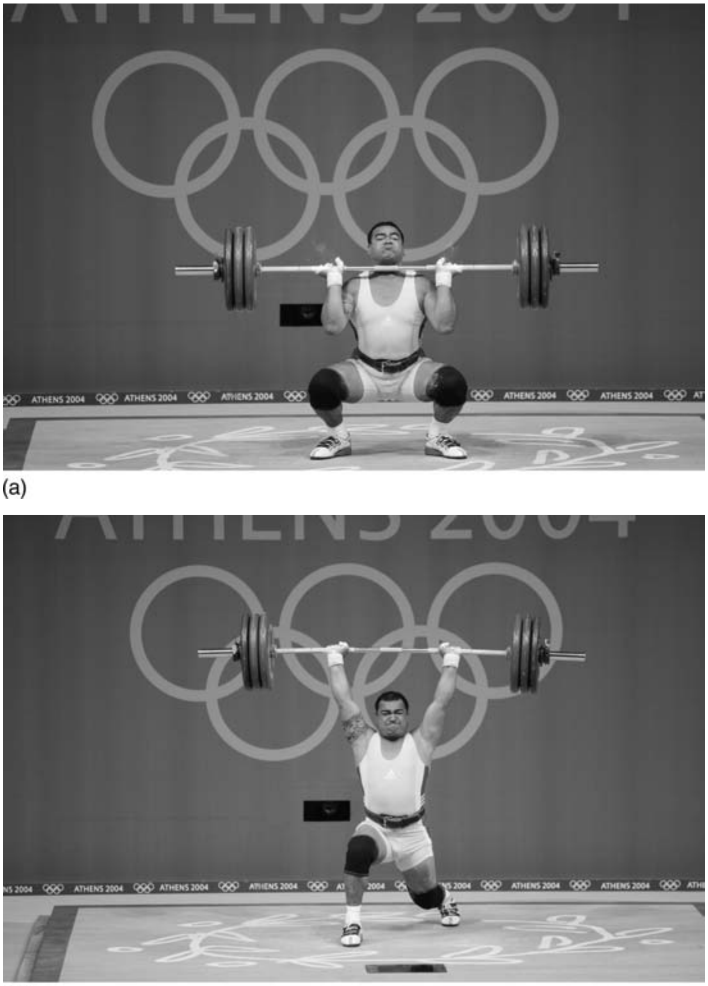

(a)

(b)

Figure 24.1 The clean and jerk exercise performed in Olympic weightlifting. (a) The lifter at the bottom of the clean, after catching the weight on the shoulders in a deep squat position. (b) The lifter near the end of the jerk, with the weight overhead and about to stand upright with the feet together to finish the lift. © IOC.

exercises will suffer numerous serious and possibly long-term injuries. The view held by some that weight training is a dangerous activity may also reflect the many case studies in which needless weight-training–related catastrophic accidents (with some resulting in death) have been reported (George et al. 1989, Stakiw & Wright 1989; Luke et al. 1990; Freeman & Rooker 1995; Gill & Mbubaegbu, 2004).

This chapter will review the research on the injury epidemiology of adults in these sports, with the primary aims being to determine the true risk of injury and to inform practice in injury prevention and prehabilitation. For a more in-depth discussion on the injury risk of weight training for children, the reader should consult any of the following articles (Faigenbaum 2000; Faigenbaum & Milliken 2003; Guy & Micheli 2001; Malina 2006).

The vast majority of the studies found were case studies in which reports of acute, traumatic injuries occurring during various forms of weight training were described. Other limitations of the literature reviewed include: (1) the small number of epidemiologic studies for the weight-training sports (particularly bodybuilding), with many of these studies reporting only some of the variables required for a full understanding of the epidemiology of injury; (2) the lack of subject characteristics such as inclusion/exclusion criteria, training experience and standard of the lifters; (3) the predominance of retrospective studies; and (4) the variance in definition of injury used.

Who Is Affected by Injury?

A summary of the studies that reported injury incidence or prevalence rates for powerlifting, weightlifting, and bodybuilding are presented in Table 24.1. The majority of these studies involved moderately small sample sizes, with only four having more than 100 subjects in their specific subgroups. There was often considerable intrastudy and interstudy variation in the age, sex, body mass, and standard of the lifters. As a result, a number of these studies have categorized (at least some of) the data by sex (Goertzen et al. 1989; Keogh et al. 2006; Ren et al. 2000), standard (Keogh et al. 2006; Raske & Norlin 2002; Ren et al. 2000), age (Keogh et al. 2006), and body-weight (mass) class (Keogh et al. 2006). However, as no significant differences in the injury incidence/frequency were observed as a function of age or body mass, these data are not included in Table 24.1.

Six studies had a definition of injury that included the requirement for each injury to be some physical damage that caused the lifter to modify or cancel at least one training session (Brown & Kimball 1983; Quinney et al. 1997; Haykowsky et al. 1999; Singh & Kaur 1999; Raske & Norlin 2002; Keogh et al. 2006). Several studies also included in their definition a requirement for each injury to be assessed by a medical practitioner (Brown & Kimball 1983; Quinney et al. 1997; Calhoon & Fry 1999; Haykowsky et al. 1999, Warburton & Quinney 1999; Singh & Kaur 1999). In contrast, the remaining studies did not provide a formal definition of injury.

When reviewing the results presented in Table 24.1, it is apparent that most of the weight-training studies in which injury incidence rates were reported gave somewhat similar results regardless of the sport or the standard or sex of the lifters (~1–2 injuries per lifter per year or ~2–4 injuries per 1,000 hours of training). The only real exception to this was the bodybuilding studies, which reported lower rates of injury (0.3–0.7 injuries per lifter per year or 1 injury per 1,000 hours) (Goertzen et al. 1989; Eberhardt et al. 2007). Because only two bodybuilding studies were found, it is difficult to be sure that such a result is indeed a true reflection of bodybuilding being less of an injury risk than the other two sports or whether it reflects variations in study design, injury definition, and so forth.

Quinney et al. (1997), Ren et al. (2000), and Singh and Kaur (1999) reported only the percentage of lifters who had suffered injuries. While Quinney et al. (1997) and Singh and Kaur (1999) limited this to the previous year, no specific time frame was provided by Ren et al. (2000). Overall, these studies found that between 50% and 90% of lifters had suffered an injury. A somewhat similar percentage (67%) of 101 powerlifters also suffered at least one injury during the course of 1 year's training (Keogh et al. 2006).

Where Does Injury Occur?

Anatomical Location

The most commonly injured anatomical locations are presented in Table 24.2. Most of these data were reported as percentage of overall injuries, with the study of Raske and Norlin (2002) the only one to also report incidence rates for each anatomical location. In descending order, the shoulder, knee, lower back, wrist/hand, and elbow were the five most commonly injured anatomical locations across all studies. However, there were some subtle between-sport differences in the most common sites of injury. In descending order, the most frequent injury sites were powerlifting (shoulder, lower back, knee, elbow), weightlifting (knee, shoulder, lower back, wrist/hand), and bodybuilding (shoulder, knee, wrist/hand, elbow).

So what may account for the between-sport differences in the most commonly injured body parts (anatomical locations)? One possible reason could be the different competitive goals and hence training practices of each of the sports (Kraemer & Koziris 1994; Fleck & Kraemer 1997). In general, weightlifters and powerlifters lift heavier loads (at a higher percentage of one repetition maximum [1RM]) for fewer repetitions with longer rest periods between sets than bodybuilders. Although there are also some obvious differences in the

Table 24.1 Summary of the frequency and incidence of weight-training injuries.

Study	Athletes	Study Design	Study Duration	No. of Injuries	Clinical Incidence (injuries/ lifter/yr)	Injury Incidence (injuries/1,000 hr of training)	Athlete Rate (% injured/yr)
Powerlifting							
Brown & Kimball (1983)	71 Junior novice M	RQ	17 mo	98	1.0	2.8	
Goertzen et al. (1989)	39 Open M	RQ and ortho exam	18 mo	120	2.1		
Goertzen et al. (1989)	21 Open F	RQ & ortho exam	18 mo	40	1.3		
Quinney et al. (1997)	31 Open elite	RQ	12 mo				55%
Haykowsky et al. (1999)	9 M and 2 F Open elite blind	RQ	12 mo	4	0.4	1.1	
Raske & Norlin (2002)[a]	50 Open elite M	RQ	24 mo	114	1.1	2.7	
Keogh et al. (2006)	82 M	RQ	12 mo	98	1.2	4.7	
Keogh et al. (2006)	19 F	RQ	12 mo	20	1.1	3.1	
Keogh et al. (2006)	36 National	RQ	12 mo	50	1.4	5.8	
Keogh et al. (2006)	65 International	RQ	12 mo	68	1.0	3.6	
Weightlifting							
Kulund et al. (1978)	80 M	RQ		111	1.4[b]		
Konig & Biener (1990)	121 M	RQ		202	1.7[b]		
Calhoon & Fry (1999)	Open elite (n = ?)	P	72 mo	560		3.3[c]	
Singh & Kaur (1999)	50 elite M	RQ	12 mo				50%
Ren et al. (2000)	195 Open M	RQ					74%
Ren et al. (2000)	70 Open F	RQ					90%
Raske & Norlin (2002)[a]	50 Open elite M	RQ	24 mo	108	1.1	2.4	
Raske & Norlin (2002)[d]	50 Open nonelite M	RQ	24 mo	98	1.0	2.9	
Bodybuilding							
Goertzen et al. (1989)	240 Open M	RQ & ortho exam	18 mo	235	0.7		
Goertzen et al. (1989)	118 Open F	RQ & ortho exam	18 mo	53	0.3		
Eberhardt et al. (2007)	250 Open M	RQ	46 mo	311	0.4	1.0	

F = female; M = male; ortho = orthopedic; P = prospective; RQ = retrospective questionnaire.
If not stated, subjects were of varying (or unknown) age, sex, and standard.
[a] Data from 2000.
[b] Total number of injuries per lifter over unknown duration.
[d] From subset of 27 resident lifters.
[d] Data from 1995.

Table 24.2 Summary of weight training injuries by most frequently anatomical locations.

Study	Athletes	Study Design	No. of Injuries	Most Frequently Injured Anatomical Locations				
				Shoulder	Lower Back	Knee	Elbow	Wrist/Hand
Powerlifting								
Brown & Kimball (1983)	71 Junior novice M	RQ	98	6%	50%	8%	6%	4%
Goertzen et al. (1989)	39 Open M	RQ & ortho exam	120	32%	33%[a]	10%	13%	6%
Goertzen et al. (1989)	21 Open F	RQ & ortho exam	40	22%	24%[a]	28%	10%	10%
Quinney et al. (1997)	31 Open elite	RQ		2nd most injured site[b]	26%			
Haykowsky et al. (1999)	9 M & 2 F Open elite blind	RQ	4	25%	25%		25%	
Raske & Norlin (2002)[c]	50 Open elite M	RQ	114	26%	15%	12%	7%	2%
Keogh et al. (2006)	82 M	RQ	98	34%	24%	10%	9%	
Keogh et al. (2006)	19 F	RQ	20	45%	20%	0%	20%	
Keogh et al. (2006)	36 National	RQ	50	42%	20%	10%	10%	
Keogh et al. (2006)	65 International	RQ	68	32%	27%	9%	12%	
Weightlifting								
Kulund et al. (1978)	80 M	RQ	111	23%	7%	23%	10%	23%
Konig & Biener (1990)	121 M	RQ	202	22%[d]	21%	25%	6%	2%
Calhoon & Fry (1999)	Open elite (n = ?)	P	560	18%	23%	19%	3%	10%
Singh & Kaur (1999)	50 elite M	RQ		2nd most injured site[b]	Most injured site[b]	3rd most injured site[b]	6th most injured site[b]	
Ren et al. (2000)	195 Open M	RQ		15%[e]	19%	29%	9%[e]	20%
Ren et al. (2000)	70 Open F	RQ			18%	32%		17%
Raske & Norlin (2002)[c]	50 Open elite M	RQ	108	14%	18%	20%	7%	10%
Raske & Norlin (2002)[f]	50 Open non-elite M	RQ	98	22%	18%	18%	9%	5%
Bodybuilding					9%			
Goertzen et al. (1989)	240 Open M	RQ & ortho exam	235	34%	10%[b]	17%	21%	16%
Goertzen et al. (1989)	118 Open F	RQ & ortho exam	53	29%	14%[b]	31%	10%	12%
Eberhardt et al. (2007)	250 Open M	RQ	311	23%	9%	5%	11%	23%

F = female; M = male; ortho = orthopedic; P = prospective; RQ = retrospective questionnaire.
If not stated, subjects were of varying (or unknown) age, sex, and standard.
[a] Entire vertebral column.
[b] No percentage given.
[c] Data from 2000.
[d] Shoulder girdle.
[e] Combined data for males and female lifters.
[f] Data from 1995.

most common exercises performed by each group, exercises such as squats, deadlifts, and shoulder presses are commonly performed by all three groups. Differences in the manner in which these exercises are performed would also affect the loading on the musculoskeletal system and hence predispose the lifters to different injuries at varying anatomical locations. The lower frequency of knee and higher frequency of lower-back injuries for powerlifters as compared with weightlifters and bodybuilders may reflect differences in the manner in which the squat and deadlift (and their derivatives) are performed by these groups.

When performing squats, powerlifters typically position the bar further down the back than the other groups. This powerlifting style squat (commonly referred to as a "low-bar squat") results in a greater forward inclination of the trunk than the high-bar/front squat performed more commonly by weightlifters and bodybuilders (Wretenberg et al. 1996, Feng & Arborelius 1996). By virtue of these differences in trunk inclination, the resistance moment arms around the knee, hip, and lower back also differ between the two squats, with the result being reduced knee extensor torques but greater hip and lower-back extensor torques for the low-bar as compared with the high-bar squat (Wretenberg et al. 1996; Escamilla et al. 2001a). Mean compressive patellofemoral forces are also lower in low- than high-bar squats (Wretenberg et al. 1996). Based on these studies, the lower frequency of knee injuries for powerlifters than weightlifters and bodybuilders may reflect the reduced mechanical stress that low-bar squats apply to the knee as compared with high-bar squats.

The increased frequency of lower-back injuries in powerlifters than weightlifters or bodybuilders may be a trade-off and reflect the manner in which their key lower-body exercises are performed. Although large lower-back compression and shear forces and torques have been reported for a number of core weightlifting and bodybuilding exercises, such as the high-bar squat, clean and jerk, and snatch (Wretenberg et al. 1996; Burnett et al. 2002, Beard & Netto 2002), even greater values have been reported for the two core powerlifting exercises – the low-bar squat (Wretenberg et al. 1996; Escamilla et al. 2001a) and deadlift (Cholewicki et al. 1991; Escamilla et al. 2000, 2001b). Overall, the subtle differences in the most commonly injured anatomical locations of injury for the three weight-training sports suggests that differences in exercise selection as well as the actual technique and body positioning in a particular exercise can make profound changes in the mechanical stress placed on specific anatomical locations and to the subsequent injury risk.

Environmental Location

No studies have documented the number of injuries that weightlifters, powerlifters and bodybuilders experience in training versus competition. This is not surprising, considering that although these athletes may train for >10 hours a week, they may compete only two to three times a year.

Based on the competitive goals of the athletes in these sports, it could be assumed that most of their injuries would occur as a consequence of lifting weights. It is, therefore, not surprising that only three studies have recorded injuries that did not occur as a direct result of weight training (Calhoon & Fry 1999; Keogh et al. 2006; Eberhardt et al. 2007). Keogh et al. (2006) observed that 13% and 15% of all injuries reported by a group of 101 powerlifters over the course of a year were a result of cross-training (e.g., ball sports or cardiovascular training) or of unknown origin, respectively. Similarly, Calhoon and Fry (1999) reported that 36% of the weightlifting injuries reported in the U.S. Olympic Training Center were not a direct result of weightlifting training. In contrast, Eberhardt et al. (2007) reported that only 1% of the injuries suffered by a group of 250 bodybuilders occurred as a result of non-weight-training (jogging) activities. Although speculative, the non-weight-training injuries reported in these studies may have actually reflected (at least in part) some chronic degeneration or muscle balance/range-of-motion imbalances attributable to the large volume of specific and intense weight training performed by these athletes (Chang et al. 1988, Buschbacher & Edlich 1988; Barlow et al. 2002). Such an argument is consistent with the dynamic model of sport-injury etiology proposed by Meeuwisse et al. (2007).

Table 24.3 Summary of onset of weight-training injuries.

Study	Athletes	Study Design	No. of Injuries	Injury Onset	
				Acute	Chronic
Powerlifting					
Raske & Norlin (2002)[a]	50 M & 10 F Open elite PL 50 M and 5 F Open elite WL	RQ	254	25%	25%
Keogh et al. (2006)	82 M	RQ	98	61%	39%
Keogh et al. (2006)	19 F	RQ	20	50%	50%
Keogh et al. (2006)	36 National	RQ	50	72%	28%
Keogh et al. (2006)	65 International	RQ	68	50%	50%
Weightlifting					
Calhoon et al. (1999)	Open elite (n = ?)	P	560	60%	30%
Ren et al. (2000)	195 Open M & 70 Open F	RQ	257	26%	42%

If not stated, subjects were of varying (or unknown) age, sex, and standard.
F = female; M = male; P = prospective; PL = powerlifters; RQ = retrospective questionnaire; WL = weightlifters.
[a] Data from 2000 and consisting of a mixed group of powerlifters and weightlifters.

When Does Injury Occur?

Injury Onset

A summary of studies reporting injury onset is provided in Table 24.3. There were no studies for bodybuilding and only two, with somewhat conflicting results for weightlifting. These studies reported the onset for all injuries collectively, with no injury-onset data given for each anatomical location. Although all of these studies recorded acute and chronic injuries, all except Keogh et al. (2006) also incorporated acute-to-chronic or "other" onset categories. With the exception of Ren et al. (2000), these studies suggest that weight-trained athletes experience a greater rate of acute- than chronic-onset injuries.

Chronometry

There are no studies that have directly examined the chronometry of injury in any of the three weight-training sports. This is unfortunate, as coaches and sports administrators can use such information to reduce injury rates in their sport. For example, as team-sport athletes suffer more injuries during the latter than during the early to middle stages of each half or quarter of a match and during the preseason than during the regular season (Hawkins & Fuller 1999; Gabbett & Domrow 2007), fatigue and a lack of "conditioning" are considered risk factors for injury in team sport athletes.

What Is the Outcome?

Injury Type

The main injury types reported in the three weight-training sports are summarized in Table 24.4. Strains, tendinitis, and sprains are generally the most common injuries; however, there were also some subtle between-sport differences. The three most common injury types for these sports were (in descending order): powerlifting (strains, tendinitis, arthritis); weightlifting (strains, tendinitis, sprains); and bodybuilding (cartilage degeneration, tendinitis, sprains). Based on these results, the two sports in which the mass lifted is the performance measure (i.e., weightlifting and powerlifting) and therefore the intensity of training (% of 1RM) is higher, the most common injury type is muscle strain. In contrast, bodybuilders, who typically train at a lower % of 1RM suffer fewer muscle but more bone and tendon injuries. Such results may indicate that the greater loads used by powerlifters and weightlifters result in a relatively higher proportion of acute-type muscle

Table 24.4 Summary of most common types of weight-training injuries.

Study	Athletes	Study Design	No. of Injuries	Injury Type				
				Arthritis	Cartilage Degeneration	Sprain	Strain	Tendinitis
Powerlifting								
Brown & Kimball (1983)	71 Junior novice M	RQ	98			4%	62%	12%
Goertzen et al. (1989)	39 Open M	RQ & ortho exam	120	29%	17%	6%	6%	28%
Goertzen et al. (1989)	21 Open F	RQ & ortho exam	40	17%	9%	17%	11%	25%
Quinney et al. (1997)	31 Open elite	RQ					38%	36%
Haykowsky et al. (1999)	9 M & 2 F Open elite blind	RQ	4				Most common injury type[a]	
Weightlifting								
Konig & Biener (1990)	121 M	RQ	202		3%	39%	29%	
Calhoon & Fry (1999)	Open elite (n = ?)	P	560			13%	45%	24%
Singh & Kaur (1999)	50 elite M	RQ				4%	47%	28%
Bodybuilding								
Goertzen et al. (1989)	240 Open M	RQ & ortho exam	235	18%	32%	6%	7%	23%
Goertzen et al. (1989)	118 Open F	RQ & orthopedic exam	53	8%	28%	13%	8%	33%
Eberhardt et al. (2007)	250 Open M	RQ	311			39%	10%	

F = female; M = male; ortho = orthopedic; P = prospective; RQ = retrospective questionnaire.
If not stated, subjects were of varying or unknown age, sex, and standard.
[a] Percentage not stated.

injuries, whereas the greater volume of exercise performed by bodybuilders results in a greater number of chronic-type connective-tissue injuries.

Time Loss

A summary of studies, none on bodybuilding reporting time loss is provided in Table 24.5. Three studies (all on powerlifting) assessed the severity of injury by recording the number of days that their training was affected by, or discontinued as a result of, each injury (Brown & Kimball 1983; Quinney et al. 1997; Haykowsky et al. 1999). These studies reported that the average injury was symptomatic for 11 to 18 days. A number of other studies also recorded the time that each injury affected training, but reported this in specific time bands such as <1 day, 1 to 7 days, 8 to 14 days, and >14 or 30 days (1 month) (Kulund et al. 1978; Konig & Biener 1990; Calhoon & Fry 1999; Raske & Norlin 2002). With the exception of Raske and Norlin (2002), all of these studies reported that the majority of weightlifting injuries were asymptomatic for <2 weeks, a value similar to that reported in the three powerlifting studies.

Another two studies (Ren et al. 2000; Keogh et al. 2006) assessed time loss associated with each injury but included within these measures the effect of injury on training. These studies reported that the majority of injuries were of mild or moderate severity in that they required modification but not discontinuation of training.

Clinical Outcome

The clinical outcome of injury can be described using various outcome measures, such as recurrent injury, catastrophic injury, nonparticipation, and residual effects. Relatively few epidemiologic data for the clinical outcome of injuries exists for the three weight-training sports. Kulund et al. (1978) reported that of the 111 injuries suffered by a group of 80 weightlifters, only 3 were recurrent. Raske and Norlin (2002) observed that over the course of a 5-year period, 38% of the elite weightlifters and powerlifters retired, with almost half (43%) of these lifters citing injury as the reason for retiring.

The potential for weight training to cause residual effects is relatively high, as arthritis and cartilage degeneration were some of the most common injury types for a comparative study of powerlifting and bodybuilding injury epidemiology (Goertzen et al. 1989). A review by Kujala et al. (2003) also supports this view in that the risk ratio (RR) for arthritis of the hip, knee, and ankle was 2.68 times higher for power athletes (weightlifters, wrestlers, boxers and track and field sprinters, jumpers and throwers) than sedentary controls. Interestingly, the risk for hip, knee, and ankle arthritis for endurance (RR, 2.37) and team sports (RR, 2.42) athletes was similar to that of the power athletes.

Although no epidemiologic studies report acute catastrophic injuries, these injuries comprise a high proportion of the case-study literature. The interested reader should refer to Lombardi (1996) for a more comprehensive overview of these weight-training–injury case studies. Not all of these studies involved competitive strength athletes; however, these case studies indicate that weight training is capable of causing muscle/tendon tears (Freeman & Rooker 1995; Leopardi et al. 2006), ligament ruptures (Freeman & Rooker 1995), bone fractures (Mayers et al. 2001; Gill & Mbubaegbu 2004) and even death (George et al. 1989; Luke et al. 1990).

So although the epidemiologic literature indicates that the chance of catastrophic injury during weight training is relatively low (with the possible exception of arthritis), weight training (in any form) can still result in serious injury and even death.

Economic Cost

The economic cost (e.g., duration and nature of treatment associated with injuries once participation is over, cost of treatment associated with injuries, and school/work time loss as a result of injury) have not been specifically reported in any of the epidemiologic studies. Nevertheless, the potential for weight training to cause long-term pain, discomfort, and disability has been investigated (Granhed & Morelli 1988; Mundt et al. 1993).

Table 24.5 Summary of severity of and time loss from weight-training injuries.

Study	Athletes	Study Design	No. of Injuries	Severity/Time Loss			
				Mild Injury	Moderate Injury	Major Injury	Time Loss/Injury
Powerlifting							
Brown & Kimball (1983)	71 Junior novice M	RQ	98				12 days
Quinney et al. (1997)	31 Open elite	RQ					18 days
Haykowsky et al. (1999)	9 M & 2 F Open elite blind	RQ	4				12 days
Raske & Norlin (2002)[a]	50 M & 10 F Open elite PL 50 M and 5 F Open elite WL	RQ	254				93% shoulder, 85% lower back & 80% knee injury >30 days
Keogh et al. (2006)	82 M	RQ	98	36%	38%	24%	
Keogh et al. (2006)	19 F	RQ	20	50%	40%	10%	
Keogh et al. (2006)	36 National	RQ	50	40%	42%	18%	
Keogh et al. (2006)	65 International	RQ	68	38%	37%	25%	
Weightlifting							
Kulund et al. (1978)	80 M	RQ	111				57% all injuries ≤14 days
Konig & Biener (1990)	121 M	RQ	202				82% knee and 76% shoulder injury ≤7 days
Calhoon & Fry (1999)	Open elite (n = ?)	Prospective					99% all injuries ≤7 day
Ren et al. (2000)	195 Open M & 70 Open F	RQ	257	45%	55%	1%	

If not stated, subjects were of varying (or unknown) age, sex, and standard.
F = female; M = male; ortho = orthopedic; P = prospective; RQ = retrospective questionnaire.
[a] Data from 2000.

Typically, these studies suggest that weight training will not cause many health and disability issues during retirement (with the possible exception of arthritis) and that weight training may actually be protective against some common age-related health issues. This is consistent with the review by Kujala et al. (2003), who found that in comparison with sedentary controls, the risk for many cardiovascular conditions were reduced in retired endurance (RR, 0.24–0.73), team (RR, 0.48–0.86), and power-sport (RR, 0.49–0.94) athletes. Similar results were observed for hospital usage, with the RR being 0.71, 0.86, and 0.95 for the endurance, team, and power-sport athletes, respectively.

What Are the Risk Factors?

Although many of the studies reviewed in this chapter state that risk factors may predispose athletes to injury, most did not test these risk factors. Even the studies that investigated possible intrinsic risk factors (Goertzen et al. 1989; Ren et al. 2000; Raske & Norlin 2002; Keogh et al. 2006) were nonexperimental cohort studies. Such studies lack the strength of randomized, controlled trials in determining the causality of injury (Hopkins et al. 2007).

Intrinsic Factors

Several nonexperimental cohort studies have examined the effect of sex (Goertzen et al. 1989; Ren et al. 2000; Keogh et al. 2006), standard (elite to novice) (Ren et al. 2000; Raske & Norlin 2002; Keogh et al. 2006), age (Open to Masters) (Keogh et al. 2006), and body-weight class (lightweight to heavyweight) (Keogh et al. 2006) on the risk of weight-training injury. A summary of these studies is provided in Table 24.1. Female lifters have similar (Ren et al. 2000; Keogh et al. 2006) or significantly lower (Goertzen et al. 1989) injury rates than male lifters. As compared with male lifters, female lifters have a significantly higher rate of knee injuries (Goertzen et al. 1989; Ren et al. 2000) but a significantly lower rate of chest and thigh injuries (Keogh et al. 2006). Although the mechanisms behind these differences are not well understood, the higher rate of knee injuries in female than male lifters is consistent with the literature for other sports and activities (Hughes & Watkins 2006).

Elite (international) lifters have a significantly lower rate of injuries than nonelite (national) lifters (Ren et al. 2000; Raske & Norlin 2002; Keogh et al. 2006). National-level lifters had significantly more chest and shoulder injuries, and international lifters more thigh injuries (Keogh et al. 2006). Although not statistically significant, Raske and Norlin (2002) also found that national lifters tended to have more chest and shoulder injuries than international lifters.

The effect of age and body-weight class on the epidemiology of weight-training injury have been assessed in only one study (Keogh et al. 2006). However, no significant differences in the overall injury rates or rates of injury at various anatomical locations were observed for powerlifters of varying age (Open vs. Masters) and body mass (lightweight vs. heavyweight).

Extrinsic Factors

Factors such as coaching and rules as well as the training environment and climate could be extrinsic factors related to injury in the weight-training sports. However, no experimental studies have so far examined this possibility in weight-trained athletes.

What Are the Inciting Events?

A number of studies reviewed in this chapter have sought to gain an idea of the events that may contribute to injury. For example, Ren et al. (2000) stated that 60% of injuries were caused by tiredness (fatigue), 31% by technical errors, and 21% by excessive overload, while Eberhardt et al. (2007) reported that most injuries were a result of improper warm-up (42%), too vigorous exercising (35%), or a lack of "spotting" (7%). However, the validity of such data is questionable, given the following factors: (1) the retrospective nature of data collection; (2) the lack of any reported definition for many of these terms;

(3) no description of how these outcomes were measured or obtained; and (4) as the percentages were greater than 100% for Ren et al. (2000), whether an injury could be caused by multiple factors. Notwithstanding these limitations, fatigue has previously been implicated as an inciting factor to injury (Hawkins & Fuller 1999; Gabbett & Domrow 2007). Lifters may therefore consider performing the most demanding, challenging, and "risky" exercises early in their training sessions and ensure that they are recovered before their next training session.

Four studies examined inciting factors by determining which exercises were most associated with injury (Kulund et al. 1978; Raske & Norlin 2002; Keogh et al. 2006; Eberhardt et al. 2007). Keogh et al. (2006) reported that the bench press and assistance exercises (i.e., all exercises that were not the squat, bench press, or deadlift) were the most common injury-causing exercises for powerlifters. Kulund et al. (1978) found that the clean and jerk, squat, and snatch were the three most commonly cited injury-causing exercises for weightlifters, whereas Eberhardt et al. (2007) observed that the bench press, shoulder press, and squat accounted for most bodybuilding injuries. In contrast, Raske and Norlin (2002) found no significant difference in the rates of shoulder injury in a mixed group of elite powerlifters and weightlifters as a function of the exercises commonly performed in training. Because the bench press, squat, clean and jerk, and snatch are competitive lifts in the sports of powerlifting and weightlifting, they are likely to be performed more frequently in training than other exercises and hence be more highly associated with injury.

As human tissues can tolerate loads of only a certain magnitude, increased mechanical loading on the musculoskeletal system can also be an inciting factor to injury. For example, lower-back injury may occur with excessive spinal flexion, an imbalance in the coactivation of the spinal and abdominal musculature, or a lack of intraabdominal pressure (Cholewicki et al. 1991; Vera-Garcia et al. 2006; Grenier & McGill 2007). The inciting mechanisms for injuries to other commonly injured anatomical locations in weight-trained athletes such as the shoulder (Madsen & McLaughlin 1984; Barlow et al. 2002) and knee (Witvrouw et al. 2000; Dugan 2005) are not currently as well understood as that for the lower back. However, these injuries may also reflect a lack of stability at the more proximal joints especially at end range or muscular endurance/strength and control imbalances.

Injury Prevention

The ultimate aim of all injury epidemiologic research must be to reduce the rate and severity of injury. While a number of authors have proposed methods to decrease injury in weight-trained athletes (Fees et al. 1998; McGill 2002, 2004), the efficacy of these approaches has yet to be experimentally determined.

Further Research

Much remains to be understood about the injury epidemiology of weightlifting, powerlifting, and bodybuilding and how the rate and severity of such injuries can be minimized. Further research in this area is, therefore, most definitely warranted. As the number of children, adolescents, and masters who participate in these weight-training sports continues to increase, research should also be conducted on these groups. This is important, as the safety of weight training, let alone the weight-training sports for these age groups is even less well understood than for young adults.

The quality of such research needs to be improved, particularly with regard to injury definition, study design, and types of data collected. It is recommended that at minimum, an injury be defined as "any physical damage that causes the lifter to modify or discontinue their regular training program." It would also be useful to confirm injury diagnosis via medical examination. Although a medical examination may be difficult to include in retrospective studies, future epidemiologic studies should strive to incorporate a prospective design and use a medical examination to increase the validity of the data especially that of injury type

(Gabbe et al. 2003). This may be most easily conducted at Institutes of Sport or Olympic Training Centers, as done by Calhoon and Fry (1999).

All studies should collect the full spectrum of epidemiologic data, particularly the variables often missing from the current literature (e.g., environmental location, onset, chronometry, clinical outcome, and economic cost). Every study should more clearly describe its inclusion and exclusion criteria and obtain data on the training performed by each athlete (e.g., training frequency, number of sets and repetitions, exercise performed, loads used) for each week's training. Such data (if involving a large enough number of subjects over a sufficient period of time) may allow some insight into how the changes in training programs influence the rate of injury in these sports.

Further cohort studies need to be conducted to determine how intrinsic factors (e.g., anthropometric profile, flexibility, muscular strength/endurance imbalances; Gross et al. 1993; Barlow et al. 2002; Keogh et al. 2007, 2008), extrinsic factors (e.g., use of weight belts; Reddell et al. 1992; Kraus et al. 2002) and inciting events (e.g., fatigue, exercise technique, selection; Fees et al. 1998; Gabbett 2000; McGill 2004) may modulate the injury risk. Such studies will inform the development of research-based injury prevention programs, which can then be tested for the efficacy in randomized, controlled trials, similar to that done for sports such as soccer and handball (Parkkari, Kujala & Kannus 2001).

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References

Barlow, J.C., Benjamin, B.W., Birt, P.J. & Hughes, C.J. (2002) Shoulder strength and range-of-motion characteristics in bodybuilders. *Journal of Strength and Conditioning Research* **16**, 367–372.

Brown, E.W. & Kimball, R.G. (1983) Medical history associated with adolescent powerlifting. *Pediatrics* **72**, 636–644.

Burnett, A., Beard, A. & Netto, K. (2002) Back stresses and assistance exercises in weightlifting. Presented at the International Symposium of Biomechanics in Sports, University of Extremadura, Caceres, Spain, pp. 421–424.

Calhoon, G. & Fry, A.C. (1999) Injury rates and profiles of elite competitive weightlifters. *Journal of Athletic Training* **34**, 232–238.

Chang, D.E., Buschbacher, L.P. & Edlich, R.F. (1988) Limited joint mobility in power lifters. *American Journal of Sports Medicine* **16**, 280–284.

Cholewicki, J., McGill, S.M. & Norman, R.W. (1991) Lumbar spine loads during the lifting of extremely heavy weights. *Medicine and Science in Sports and Exercise* **23**, 1179–1186.

Dugan, S.A. (2005) Sports-related knee injuries in female athletes: what gives? *American Journal of Physical Medicine and Rehabilitation* **84**, 122–30.

Eberhardt, A., Dzbański, P., Fabirkiewicz, K., Iwański, A. & Ronge, P. (2007) Frequency of injuries in recreational bodybuilding. *Physical Education and Sport* **51**, 40–44.

Escamilla, R.F., Fleisig, G.S., Lowry, T.M., Barrentine, S. & Andrews, J. (2001a) A three-dimensional biomechanical analysis of the squat during varying stance widths. *Medicine and Science in Sports and Exercise* **33**, 984–998.

Escamilla, R.F., Fleisig, G.S., Zheng, N., Barrentine, S., Wilk, K. & Andrews, J. (1998) Biomechanics of the knee during closed kinetic chain and open kinetic chain exercises. *Medicine and Science in Sports and Exercise* **30**, 556–569.

Escamilla, R.F., Francisco, A., Fleisig, G.S., Barrentine, S., Welch, C., Kayes, A. & Andrews, J. (2000) A three-dimensional biomechanical analysis of sumo and conventional style deadlifts. *Medicine and Science in Sports and Exercise* **32**, 1265–1275.

Escamilla, R.F., Lowry, T.M., Oshbar, D.C. & Speer, K.P. (2001b) Biomechanical analysis of the deadlift during the 1999 Special Olympics World Games. *Medicine and Science in Sports and Exercise* **33**, 1345–1353.

Faigenbaum, A.D. (2000) Strength training for children and adolescents. *Clinics in Sports Medicine* **19**, 593–619.

Faigenbaum, A.D. & Milliken, L.A. (2003) Maximal strength testing in healthy children. *Journal of Strength and Conditioning Research* **17**, 162–166.

Fees, M., Decker, T., Snyder-Mackler, L. & Axe, M.J. (1998) Upper extremity weight-training modifications for the injured athlete: a clinical perspective. *American Journal of Sports Medicine* **26**, 732–42.

Fleck, S.J. & Kraemer, W.J. (1997) *Designing Resistance Training Programs*, Human Kinetics, Champaign, IL.

Freeman, B.J. & Rooker, G.D. (1995) Spontaneous rupture of the anterior cruciate ligament after anabolic steroids. *British Journal of Sports Medicine* **29**, 274–5.

Gabbe, B.J., Finch, C.F., Bennell, K.L. & Wajswelner, H. (2003) How valid is a self reported 12 month sports injury

history? *British Journal of Sports Medicine* **37**, 545–547.
Gabbett, T.J. (2000) Incidence, site, and nature of injuries in amateur rugby league over three consecutive seasons. *British Journal of Sports Medicine* **34**, 98–103.
Gabbett, T.J. & Domrow, N. (2007) Relationships between training load, injury, and fitness in sub-elite collision sport athletes. *Journal of Sports Sciences* **25**, 1507–1519.
Garhammer, J. (1993) A review of power output studies of Olympic and powerlifting: methodology, performance prediction, and evaluation tests. *Journal of Strength and Conditioning Research* **7**, 76–89.
George, D.H., Stakiw, K. & Wright, C.J. (1989) Fatal accident with weight-lifting equipment: implications for safety standards. *Canadian Medical Association Journal* **140**, 925–6.
Gill, I.P. & Mbubaegbu, C. (2004) Fracture shaft of clavicle, an indirect injury from bench pressing. *British Journal of Sports Medicine* **38**, E26.
Goertzen, M., Schoppe, K., Lange, G. & Schulitz, K.P. (1989) Injuries and damage caused by excess stress in body building and power lifting. *Sportverletz Sportschaden* **3**, 32–6.
Granhed, H. & Morelli, B. (1988) Low back pain among retired wrestlers and heavyweight lifters. *American Journal of Sports Medicine* **16**, 530–3.
Grenier, S.G. & McGill, S.M. (2007) Quantification of lumbar stability by using 2 different abdominal activation strategies. *Archives of Physical Medicine and Rehabilitation* **88**, 54–62.
Gross, M.L., Brenner, S.L., Esformes, I. & Sonzogni, J.J. (1993) Anterior shoulder instability in weight lifters. *American Journal of Sports Medicine* **21**, 599–603.
Guy, J.A. & Micheli, L.J. (2001) Strength training for children and adolescents. *Journal of the American Academy of Orthopaedic Surgeons* **9**, 29–36.
Hawkins, R.D. & Fuller, C.W. (1999) A prospective epidemiological study of injuries in four English professional football clubs. *British Journal of Sports Medicine* **33**, 196–203.
Haykowsky, M.J., Warburton, D.E.R. & Quinney, H.A. (1999) Pain and injury associated with powerlifting training in visually impaired athletes. *Journal of Visual Impairment and Blindness* **93**, 236–241.
Hopkins, W.G., Marshall, S.W., Quarrie, K.L. & Hume, P.A. (2007) Risk factors and risk statistics for sports injuries. *Clinical Journal of Sport Medicine* **17**, 208–210.
Hughes, G. & Watkins, J. (2006) A risk-factor model for anterior cruciate ligament injury. *Sports Medicine* **36**, 411–28.
Keogh, J., Hume, P.A. & Pearson, S. (2006) Retrospective injury epidemiology of one hundred one Oceania competitive power lifters: the effects of age, body mass, competitive standard, and gender. *Journal of Strength and Conditioning Research* **20**, 672–681.
Keogh, J.W.L., Hume, P.A., Pearson, S.N. & Mellow, P. (2007) Anthropometric dimensions of male powerlifters of varying body mass. *Journal of Sports Sciences* **25**, 1365–1376.
Keogh, J.W.L., Hume, P.A., Pearson, S.N. & Mellow, P. (2008) To what extent does sexual dimorphism exist in competitive powerlifters? *Journal of Sports Sciences* **26**, 531–541.
Konig, M. & Biener, K. (1990) Sport-specific injuries in weight lifting. *Schweizische Zeitschrift fur Sportmedizin* **38**, 25–30.
Kraemer, W. J., & Koziris, L. P. (1994). Olympic weightlifting and powerlifting. In D. R. Lamb, H. G. Knuttgen & R. Murray (Eds.), Physiology and Nutrition for Competitive Sport (pp. 1-54). Carmel, IN: Cooper.
Kraus, J.F., Schaffer, K.B., Rice, T., Maroosis, J. & Harper, J. (2002) A field trial of back belts to reduce the incidence of acute low back injuries in New York City home attendants. *International Journal of Occupational and Environmental Health* **8**, 97–104.
Kujala, U.M., Marti, P., Kaprio, J., Hernelahti, M., Tikkanen, H. & Sarna, S. (2003) Occurrence of chronic disease in former top-level athletes: predominance of benefits, risks or selection effects? *Sports Medicine* **33**, 553–61.
Kulund, D.M., Dewey, J.B., Brubaker, C.E. & Roberts, J.R. (1978) Olympic weight-lifting injuries. *Physician and Sportsmedicine* **6**, 111–118.
Leopardi, P., Vico, G., Rosa, D., Cigala, F. & Maffulli, N. (2006) Reconstruction of a chronic quadriceps tendon tear in a body builder. *Knee Surgery, Sports Traumatology, Arthroscopy* **14**, 1007–1011.
Lombardi, V.P. (1996) Resistance training. In: *Epidemiology of Sports Injuries* (Caine, D.J., Caine, C.G. & Lindner, K.J., eds.), Human Kinetics, Champaign, IL: 312–336.
Luke, J.L., Farb, A., Virmani, R. & Sample, R.H. (1990) Sudden cardiac death during exercise in a weight lifter using anabolic androgenic steroids: pathological and toxicological findings. *Journal of Forensic Science* **35**, 1441–1447.
Madsen, N. & McLaughlin, T. (1984) Kinematic factors influencing performance and injury risk in the bench press exercise. *Medicine and Science in Sports and Exercise* **16**, 376–381.
Malina, R.M. (2006) Weight training in youth-growth, maturation, and safety: an evidence-based review. *Clinical Journal of Sport Medicine* **16**, 478–87.
Mayers, L.B., Khabie, V., Castorina, R. & Styles, S.T. (2001) Acute transverse patellar fracture associated with weightlifting: case report and literature review. *American Journal of Sports Medicine* **29**, 232–3.
McGill, S.M. (2002) *Low Back Disorders: Evidence-Based Prevention and Rehabilitation,* Human Kinetics, Champaign, IL.
McGill, S.M. (2004) *Ultimate Back Fitness and Performance,* Wabuno Publishers, Waterloo, ON.
Meeuwisse, W.H., Tyreman, H., Hagel, B. & Emery, C. (2007) A dynamic model of etiology in sport injury: the recursive nature of risk and causation. *Clinical Journal of Sport Medicine* **17**, 215–219.
Mundt, D.J., Kelsey, J.L., Golden, A.L., Panjabi, M.M., Pastides, H., Berg, A.T., Sklar, J. & Hosea, T. (1993) An epidemiologic study of sports and weight lifting as possible risk factors for herniated lumbar and cervical discs. *American Journal of Sports Medicine* **21**, 854–60.
Parkkari, J., Kujala, U.M. & Kannus, P. (2001) Is it possible to prevent sports injuries? Review of controlled clinical trials and recommendations for future work. *Sports Medicine* **31**, 985–995.
Quinney, H.A., Warburton, D.E.R., Webster, A., Calvert, R. & Haykowsky, M.J. (1997) Powerlifting injuries associated with elite powerlifting training. *Canadian Journal of Applied Physiology* **20**, 49.
Raske, A. & Norlin, R. (2002) Injury incidence and prevalence among elite weight and power lifters. *American Journal of Sports Medicine* **30**, 248–56.

Reddell, C.R., Congleton, J.J., Huchingson, D.R. & Montgomery, J.F. (1992) An evaluation of a weightlifting belt and back injury prevention training class for airline baggage handlers. *Applied Ergonomics* **23**, 319–29.

Ren, Y.H., Rong, J.H., Shi, H.F., Wang, W.Y. & Xi, H.X. (2000) An epidemiological survey and comparative study of the injuries in weightlifting. *Sports Science* **20**, 44–46;92.

Singh, G. & Kaur, B. (1999) Injury rates of elite competitive weightlifters. *5th IOC World Congress on Sport Sciences with the Annual Conference of Science and Medicine in Sport*, Sydney, p. 231.

Vera-Garcia, F.J., Brown, S.H., Gray, J.R. & McGill, S.M. (2006) Effects of different levels of torso coactivation on trunk muscular and kinematic responses to posteriorly applied sudden loads. *Clinical Biomechanics* **21**, 443–55.

Witvrouw, E., Lysens, R., Bellemans, J., Cambier, D. & Vanderstraeten, G. (2000) Intrinsic risk factors for the development of anterior knee pain in an athletic population: a two-year prospective study. *American Journal of Sports Medicine* **28**, 480–9.

Wretenberg, P., Feng, Y. & Arborelius, U.P. (1996) High- and low-bar squatting techniques during weight-training. *Medicine and Science in Sports and Exercise* **28**, 218–224.

Chapter 25

Wrestling

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Introduction

Wrestling, arguably the world's oldest sport and certainly comparable in age to track and field, can be traced back for over 5,000 years. It was part of the ancient Olympics by 708 B.C. With the dawn of the modern Olympics in 1896, wrestling was again featured on the program only to be briefly dropped in 1900. In 1904 it regained its place as an Olympic event and has remained so, albeit with some evolution, to the present.

Two styles of wrestling are seen in the Olympics: Greco-Roman and freestyle or "catch as catch can." Greco-Roman style—in which holds below the waist, holds using the legs and tripping involving the lower extremities are prohibited—actually developed in France during the Napoleonic era; it was the style seen in the inaugural games of the modern Olympics in 1896. Freestyle, in which no holds are barred, except rule-defined illegal holds or moves seen by the referee as potentially dangerous to the wrestlers, was added to the Olympics as a trial in 1904. Both styles have been continually contested in the Olympics since 1920. In place of either Olympic style, "folk-style" wrestling is widely practiced in high schools and colleges in the United States.

Wrestlers are matched by prescribed weight classes. There were 10 weight classes in Olympic wrestling until the 2000 Games in Sydney, when the number was reduced to 8. In 2004 the number was reduced to 7, and women's wrestling was added to the Olympic program with 4 weight classes.

This chapter reviews the literature on injuries in wrestling, as well as infections, particularly of the skin, to provide a useful overview of morbidity risks associated with Olympic-style wrestling. Our goal is to report current knowledge on the epidemiology of injury in Olympic-style wrestling, to suggest measures for injury reduction and prevention, and to propose directions for future research in these areas. However, since there are few studies devoted specifically to Olympic wrestling populations, literature concerning wrestling in general, predominantly from folk style in the United States, is included.

Who Is Affected by Injury?

Many studies have attempted to quantify injury rates in wrestling. Unfortunately, they are, for the most part, not comparable because of varying definitions of injury and exposure, the differing populations studied, and varying methods of data collection. For instance, in the 30 sources reviewed for data on overall injury rates only 4 (Jarrett et al. 1998; Agel et al. 2007; Fernandez et al. 2007; Yard et al. 2008) used an identical rigorous injury definition (the definition used by the National Collegiate Athletic Association (NCAA) Injury Surveillance System (ISS) in the United States). Twenty-three differing injury definitions were found in the literature.

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Table 25.1 Comparison of injuries in high-school and college wrestling.

Study	Study Design	Data-Collection Method	Duration	No. of Injuries	No. of Wrestlers[a]	No. of AEs	No. of Teams	Rate/100 Participants	Rate/1,000 AEs
College									
Roy (1979)	R	I	3 seasons	332	115		1	288	
Jackson et al. (1980)	R	D	2 yr	17	89			19.1	
Powell (1981)	P	I	5 seasons	2,129	2,255		87	94	9.5
Snook (1982)	R	I	5 seasons	90	129		1	69.8	
Wroble & Albright (1986)	R	I	8 seasons	847	464		1	176	
NCAA (1993)	P	I	8 seasons	5,999			343		9.4
Jarrett et al. (1998)	R	D	11 seasons	8,425		873,479	45/yr		9.6
Dane et al. (2004)	P	I		36	58		1	62.0	
Yard et al. (2008)	P	I	1 season	258		35,599	15		7.25
High school									
Garrick & Requa (1978)	P	I	2 seasons	176	234		4	75	
Zariczny et al. (1980)[b]	P	I	1 year	27	165			16.4	
Estwanik & Rovere (1983)	P	Q	2 seasons	248	1,091		49	22.7	
NHSIR (1989)[c]	P	I	1 season	690	1,387		47	50	
NHSIR (1989)[d]	P	I	2 seasons				47		7.6
McLain & Reynolds (1989)	P		1 yr	26	65			40.0	
de Loes (1995)	R	D	3 yr	105	4,927	167,085			6.3
Beachy et al. (1997)	P	I	8 yr	1,081	594		3/yr	182.0	
Kvittem et al. (1998)	P	Q	1 season	392	101			388.1	
Powell & Barber-Foss (1999)	P	I	3 yr	2910		522,608		26.70	5.6
Pasque & Hewett (2000)	P	I	1 season	219	418	36,473	14	52.0	6
Comstock et al. (2006)	P	I	1 season						2.5
Emery et al. (2006)	R	Q	1 yr					55[e]	
Yard et al. (2008)	P	I	1 season	387		166,279			2.33
Knowles et al. (2006)	P	I	3 seasons	154	1115				1.49
International									
Lok & Yuceturk (1975)	R	I	1 season	31	128		1	24.2	

AE = athlete-exposure; D = data review; I = interview; NCAA = National College Athletic Association; NHSIR = National High School Injury Registry; P = prospective; Q = questionnaire; R = retrospective.

[a] Male, unless otherwise indicated.

[b] Includes ages 5–18 yr.

[c] Data from 1987–1988 only.

[d] Data includes 1987–1988 and 1988–1989 seasons.

[e] No. of injuries/100 participants/yr (estimated from figures).

Three studies, by Dane et al. (2004), Estwanik et al. (1980), and Kraus & Conroy (1984), did not specifically define "injury."

Table 25.1 summarizes the data for injury rates in wrestling as expressed in the most comparable studies, subdivided according to whether the population studied was high school, college, or international. Clinical incidence (injuries per 100 wrestlers) averaged 96.6 (range, 19.1–388.1) across the studies. Injury rates based on exposure data (e.g., rate per 1,000 athlete-exposures [AEs]) ranged from 2.3 to 9.6, with definite clustering in the range of 7.3 to 9.6 per 1,000 AEs.

When compared with other sports engaged in by males of comparable ages, wrestling consistently ranked behind tackle football in risk (Beachy et al. 1997) and rate per AE (Powell & Barber-Foss 1999a; Caine et al. 2006; Comstock et al. 2006).

Female involvement in wrestling is a relatively new phenomenon, and sex -specific injury rate data are few. In a retrospective study of sport participation and injury in a Canadian high school population, Emery et al. (2006) reported 56 injuries per 100 female wrestling participants per year, compared with 54 injuries per 100 male participants.

The question of injury rates as related to weight class has been evaluated in studies reporting clinical incidence, and the consensus is that injury rates are evenly distributed across weight classes, with a tendency toward slightly higher rates in the middle-weight classes (Estwanik, Bergfeld & Canty 1978; Wroble et al., 1986; McGuine 1989; Hoffman & Powell, 1990; Lorish et al., 1992). This trend was also observed by Agel et al. (2007) in their review of college wrestling injuries from 1988 to 2004. Notably, Boden et al. (2002) and Kordi, Akbarnejad, and Wallace (2008) reported more catastrophic injuries in the low- and middle-weight classes.

Where Does Injury Occur?

Anatomical Location

The distribution of injuries by anatomical location for college and high-school wrestlers is shown in Tables 25.2 and 25.3, respectively.

Examination of the data for college wrestlers (Table 25.2) shows that the regions most commonly injured are the head/spine/trunk (12.5–51.8%) and lower extremity (24.8–45.1%), followed by the upper extremity (13.4–35.8%). However, a 16-year report of NCAA wrestlers (Agel et al. 2007) revealed the lower extremity to be the region most affected by injury (38.2%; specifically the knee, 11.2–29%), followed by the head/spine/trunk (12.5%) and upper extremity (13.4%; specifically the shoulder, 5–22.4%).

A review of the data for high-school wrestlers (Table 25.3) shows that the regions most commonly affected are the head/spine/trunk (24.5–48%), followed by the upper extremity (9.3–42%; shoulder, 3.5–18.6%) and lower extremities (7.5–42.3%; knee, 1.2–38.4%).

As shown in Tables 25.2 and 25.3, skin infections have been reported to contribute from 5% to 21.6% and from 16.7% to 20.3% of all injuries sustained by high-school and college wrestlers, respectively. Table 25.4 shows that any type of skin infection may affect as many as 4.2% to 54% of wrestlers. The head/face/neck region is consistently the most affected (50–75.7%) in studies on location of skin infections, followed by the extremities (9.1–42%) and trunk (1.8–28%). Herpes gladiatorum alone has been reported to affect as many as 2.6% to 36.8% of high-school and college wrestlers studied.

Several studies have reported rate data for injuries by anatomical location, including rates for ankle (Nelson et al. 2007), lower-extremity (Fernandez et al., 2007), orofacial (Kvittem et al. 1998), and dental (Beachy 2004) injuries.

Environmental Location

Practice versus Competition

The proportion of injuries is greater in practice than competition at both high-school (62–68% vs. 27–38%) and college (74–89% vs. 11–26%) levels. However, when exposure-based injury rates for practice and competition are compared, the rate of injury is consistently greater in competition than in practice across all studies, including high school (1.83 vs. 8.1 injuries/1,000 AEs) and college (3.9 vs. 30.7 injuries/1,000 AEs) wrestling (Garrick & Requa 1978; Roy 1979; Zaricznyj et al. 1980; Powell 1981; Jarrett et al. 1998; Powell & Barber-Foss 1999; Agel et al. 2007; NCAA 2008; Rechel, Yard & Comstock 2008; Yard et al. 2008). Powell and Barber-Foss (1999a) reported an incidence density ratio of

Table 25.2 Percent comparison of college injuries by anatomical location.

	Patacsil 1955	Lok & Yuceturk 1975	Estwanik et al. 1978	Roy 1979	Powell 1981	Strauss & Lanese 1982	Snook 1982	Wroble & Albright 1986	McGuine 1989	NCAA 1993	Jarrett et al. 1998	Dane et al. 2004	Agel et al. 2007	Yard et al. 2008
Level	C	IN	OT	C	C	Y, HS, C	C	C	C	C	C	C	C	C
Study design	P	R	P	R	P	P	R	R	P	P	R	P	R	P
Skin				**16.9**			**16.7**						**12.6**	**20.3**
Head/spine/trunk	**30.8**	**25.7**	**49**	**34.2**	**31.9**	**48**	**24.3**	**40.6**	**51.8**	**35**			**12.5**	**34.1**
Head	3.3		5.1	3.3			1.1	3.1		4.9	4	12.5[a]	3.3	
Face/mouth	1.7		9.2	2.7			3.3	8.2		7.6	5		1.7	
Ear	5		7.1	6.9			2.2	5.4		1.7				
Nose	2.5	3.2		1.8		29.4	1.1		43.3	0.7			0.3	
Eye	1.7				20.4		1.1			1.8				
Teeth	0.8			0.3				2.4		0.2				
Neck	0.8	6.4	8.2	8.4			5.5	12		5.9	6		3.2	
Upper back	2.5			1.5				4.7		2.1				3.9
Lower back	3.3		5.1	2.4		18.6	3.3		8.5	4.9	4		2.0	
Rib/chest	9.2	16.1	14.3	6.9	11.5		6.7	4.8		4.5	5	2.5	2.0	
Andomen										0.7				
spine												10		
Upper extremity	**35.8**	**29**	**22.4**	**19.5**	**21.4**	**20.6**	**31.1**	**20.5**	**22.4**	**27.0**			**13.4**	**24.4**
Shoulder	20.8	22.4	16.3	8.4			17.8	11.4		13.3	14	5	10.6	17.8
Arm	1.7				10.9			4.6[b]		1.8				0.8
Elbow	8.3	3.2	5.1	3.9			7.8			4.2	5	7.5[b]	1.7	2.3
Wrist		3.2	1			20.6			22.4	0.85				0.4
Forarm				0.3			5.5			2.6				
Hand/finger	5			6.9	10.5			4.5[c]		4.2		5.0[c]	1.1	3.1
Lower extremity	**31.1**	**45.1**	**26.4**	**28.6**	**41.8**	**31.4**	**27.7**	**38.7**	**24.8**	**34.9**		**32.5**	**38.2**	**41.1**
Pelvis/hip		3.2	1	1.2				3.9		1.8			0.3	6.6[d]
Thigh	1.7	3.2	7.1	1.5	5.3		3.3			3.1	2		1.2	
Knee	18.3	29	11.2	15.4	26		20	25.4		19.5	21	25	18.3	15.4
Leg	0.8			2.4		31.4		8.1	24.8	1.7				1.2
Ankle	10	9.7	5.1	6			4.4			7.3	9		7.4	6.9
Heel/foot/toe	0.8		2	2.1	10.5			1.3		1.5		32.5[e]	11.0	1.5
Other	**1.7**		**2**	**0.3**	**4.9**					**3.2**			**2.4**	**0.4**
Total no. of injuries	**120**	**31**	**98**	**331**	**2,129**	**102**	**90**	**866**	**129**	**1,055**	**8425**	**36**	**9,723**	**258**
Total no. of participants	**711**	**128**	**459**	**115**	**2,255**	**1,059**	**129**	**464**	**341**			**58**		

C = college; HS = high school; IN = international; OT = Olympic trials; P = prospective; R = retrospective; Y = youth (ages 6–16 yr).
[a]Includes back.
[b]Includes forearm.
[c]Includes wrist.
[d]Includes upper leg.
[d]Includes ankle.

Table 25.3 Percent comparison of high-school injuries by anatomical location

	Konrad	Brown	Patacsil	Acksel	Estwanik et al.	Requa & Garrick	Powell & Barber-Foss	Strauss & Lanese[a]	Estwanik & Rovere	NHSIR	Lorish et al.[b]	Pasque and Hewett	Yard et al.
	1951	1951	1955	1966	1980	1981	1999	1982	1983	1988	1992	2000	2008
Study design	P	R	P	R	R	P	P	P	P	P	P	P	P
Skin	**21.6**	**15.9**									**6.8**	**5**	**8.5**
Head/spine/trunk	**39.5**	**36.2**	**47.2**	**45.35**	**24.5**	**37.5**	**28.4**	**48**	**31.9**	**32.5**	**43.9**	**27**	**28.2**
Head			1.2	3.8			9.5[c]				6.3	8	
Face/mouth			2.5	1			7[d]				2.3		
Ear	23.4	24.6	16.2	17.3	7.6	3.6					0.9		
Nose	1.2		2.5	0.7	5.7			29.4	16.1		1.8		
Eye			3.7							15.6	4.1		
Teeth			2.5	2.1									
Neck	3.6		8.7	3.5							14.9	11[e]	6.8
Upper back			2.5										
Lower back	4.7		1.2	8.3	6.2	33.9		18.6	8.1		7.7		
Rib/chest	6.6	11.6	6.2	8.3	5				7.7	17	5.4	8	
Abdomen				0.35			11.9				0.5		
Spine													
Upper extremity	**9.3**	**26.1**	**22.4**	**32.8**	**26.2**	**29.1**	**32.6**	**20.6**	**37.1**	**33.7**	**33.0**	**42**	**39.2**
Shoulder	3.5		7.5	10.7	16.2		18.4[f]		14.9		16.7	24	18.6
Arm	0.8			1.4		23.2				16.5	1.4		1.8
Elbow	1		3.7	7.3	5				9.3		3.6	7	10.1
Wrist	2.8	26.1		4.8				20.6			2.7		1.7
Forarm													
Hand/finger	1.2		11.2	8.6	5	5.9	14.2[g,h]		12.9	17.2	8.6	11[h]	7
Lower extremity	**7.5**	**21.7**	**29.9**	**21.45**	**42.3**	**33.3**[i]	**27.2**	**31.4**	**20.9**	**28.6**	**14.5**	**28**	**32.3**
Pelvis/hip			2.5	2.1			5.4[j,k]				1.8		
Thigh			2.5	0		1.2				5.9			
Knee	1.2		13.7	9.3	38.4	19.6	14.8		14.1	14.2	7.7	17	15.4
Leg		21.7						31.4					2.9
Ankle	6.3		8.7	9.7	3.9	5.4			6.8		3.2		6.4
Heel/foot/toe			2.5	0.35			7.0[l]			8.6	1.8	11[l]	1.1
Other	**21.4**			**0.35**	**7.1**		**11.7**		**10.1**	**4.9**	**0.9**		**0.4**
Total no. of injuries	**735**	**69**	**80**	**289**	**666**	**168**	**1582**	**102**	**248**	**690**	**221**	**219**	**99,577**
Total no. of participants	**4,835**	**201**	**907**	**2,032**		**234**	**2255**	**1,059**	**1,091**	**1,387**	**1742**	**418**	

NHSIR = National High School Injury Registry; P = prospective; R = retrospective.
[a] Includes college, high school, and youth (ages 6–16 yr).
[b] Youth (ages 6–16 yr).
[c] Includes neck and spine.
[d] Includes scalp.
[e] Includes back.
[f] Includes arm.
[g] includes forearm.
[h] includes wrist.
[i] Total consists of 7.1% injuries described as lower extremity, other.
[j] Includes leg.
[k] Includes thigh.
[l] Includes ankle.

Table 25.4 Percent comparison of skin conditions and infections.

Study	Study Design	Data-Collection Method	Duration	Type of Skin Infection	Participants	No. of Infections	Percentage Infected	Head, Face, Neck	Extremities	Trunk
High School										
Becker et al. (1988)	R	Q	1season	HG	2,354	62	2.6%			
Belongia et al. (1991)	R	I	1 camp	HG	175	60	34%	73%	42%	28%
Pasque & Hewett (2000)	P	I[a]	1 season	Any type	418	19	5%			
Anderson (2003)[b]	R	I[a]	1 tournament	HG		61				
	R		28-day camp	HG	300	33		75.7%	9.1%	15.2%
	R		28-day camp	HG	330	57		71.9%	26.4%	1.8%
Anderson (2007)	R	I	Tournament (10 yr)	Any type	7140	299	4.2%			
Yard et al. (2008)	P	I	1 yr	Any type		36		50%	32.6%	5.6%
College										
Porter & Baughman (1965)	P	I[a]	1 season	Herpes simplex	19	7	36.8%			
Roy (1979)	R	Q	3 yr	Any type	115	56	48.7%			
Becker et al. (1988)	R	Q	1 season	HG	2,625	199	7.6%			
	R	I	1 season	Any type	48	26	54%			22
Agel et al. (2007)	R	I	16 seasons	Any type		1227				
Yard et al. (2008)	P	I	1 yr	Any type		68				

HG = herpes gladiatorum; I = interview; P = prospective; Q = questionnaire; R = retrospective.
[a] Includes physical examination, review of medical charts, or both.
[b] Wrestling camp, ages 13–18 yr.

1.7 (SD = 0.06) and Rechel et al. (2008) reported a rate ratio of 1.93 (95% confidence interval [CI], 1.58–2.35), indicating a significant increased risk of injury during competition. Jarrett et al. (1998) reported a significant difference ($P < 0.0001$) between competition (30.7 injuries per 1,000 AEs) and practice (7.2 injuries per 1,000 AEs).

Several studies have reported differences in rates of specific injury types between practice and competition. Wroble et al. (1986) studied knee injuries in a university wrestling team over 6 years, and found a rate of 92.4 per 100,000 minutes of competition exposure versus 2.4 injuries per 100,000 minutes of practice exposure. Boden et al. (2002) found that 80% of catastrophic injuries occurred during matches.

Tournament Studies

A comparison of injury rates reported in tournament studies is provided in Table 25.5 and indicates higher rates in college (8.1–22 injures per 100 matches) as compared with high-school and youth studies (2.1–11 injuries per 100 matches). However, Strauss and Lanese (1982) found that the rate for high-school wrestlers was only slightly higher than for college wrestlers. These varying injury rates may be due to differences in injury definition or to changes in rules and style over time (Yard & Comstock 2007).

Two tournament studies using a similar definition of a reportable injury, conducted three decades apart, are the only studies to date to compare injury rates in the Olympic freestyle and Greco-Roman wrestling (Table 25.5). Estwanik et al. (1978) found that in the U.S. Olympic wrestling trials, the injury rate for freestyle and Greco-Roman wrestling was 7.27 and 3.1 injuries per 100 matches, respectively. In contrast, Yard & Comstock (2007) reported rates of 0.7 and 0.46 injury per 100 matches for freestyle and Greco-Roman wrestling, respectively.

When Does Injury Occur?

Injury Onset

No studies were located that reported the ratio of acute to chronic injuries in wrestling.

Chronometry

A few studies have looked at when, during a wrestling match, injury is most likely to occur. Kersey and Rowan (1983), studying an NCAA championship tournament, found that 19.1% of injuries occurred in the first period, 28.2% in the second, and 52.7% in the third. Pasque and Hewett (2000), studying a high-school population, found no evidence that injuries clustered in any particular time period in practice or matches.

Several studies have looked at the distribution of injuries prior to and throughout the wrestling season. Agel et al. (2007) showed that for college wrestlers the preseason practice injury rates were almost twice as high as regular-season practice injury rates (RR, 1.8; 95% CI, 1.7–1.9; $P < 0.01$). They also reported greater preseason match rates than regular-season match rates (RR, 1.5; 95% CI, 1.3–1.8; $P < 0.01$). Similarly, Jarrett et al. (1998) and Wroble et al. (1986) reported higher rates of high-school wrestling injuries early during the wrestling season. Notably, Wroble et al. (1986) found that more than three times as many knee injuries occurred during the first month as compared with any other month in the wrestling season.

What Is the Outcome?

Injury Type

A summary of studies on types of injuries sustained by wrestlers is provided in Table 25.6. This table shows that the most common injury types for college wrestlers are sprains (23.8–42.2%), followed by infections (16.7–39.6%) and tendinitis/strains (3.3–31.9%). In contrast, tendinitis/strains were more common among high-school wrestlers (23–30.6%), followed by sprains (22.8–30%). Rechel et al. (2008) reported sprains/strains to be the most common injury type involving time loss among high-school wrestlers in both practice and competition, followed by fractures and contusions.

Several studies have provided rate data for specific injury types, including patellar tendinitis (Lian et al. 2005), concussion (Schultz et al. 2004), and mild traumatic brain injury (Powell & Barber-Foss 1999b).

Table 25.5 Comparison of injury rates in tournament studies.

Study	Level	Data-Collection Methods	Study Design	Duration	No. of Injuries	No. of Wrestlers	No. of Matches	Injuries/ 100 Wrestlers	Injuries/ 100 Matches
Youth									
Hartmann (1978)	Y[a]	I	P	1 tournament	21		190		11
Strauss & Lanese (1982)	Y[b]	I	P	1 tournament	11	291	525	3.8	2.1
Lorish et al. (1992)	Y[c]	I	P	2 tournament	221	1,742	7,196	12.7 9.7[d] 22.1[e]	3.1
High School									
Strauss & Lanese (1982)	HS[b]	I	P	4 tournament	58	520	676	11.1	8.6
College									
Strauss & Lanese (1982)	C[b]	I	P	2 tournament	33	238	406	13.9	8.1
Kersey & Rowan (1983)	C	I	P	1 tournament	110	353	493	31.2	22
McGuine, 1989	C	I	P	1 tournament	129	341	628	38	21
National									
Estwanik et al. (1978) (adult)	Freestyle	I	P	1 tournament	83	313	1,141	26.5	7.27
	Greco-Roman	I	P	1 tournament	15	146	499	10.2	3.1
Yard & Comstock (2007) (pediatric)	Freestyle	I	P	1 tournament	83				0.7
	Greco-Roman	I	P	1 tournament	55				0.46

HS = high school; I = interview; P = prospective; Q = questionnaire; Y = youth.
[a]Ages 7–12 yr.
[b]Four tournaments: 1 youth, 1 HS, 2 college.
[c]Ages 6–16 yr.
[d]Injury rate for 6- to 8-year-olds.
[e]Injury rate for 14- to 16-year-olds.

Time Loss

Several studies of high-school wrestlers have reported time loss as an indicator of injury severity (Garrick & Requa 1978; Roy 1979; Garrick & Requa, 1981, Powell 1981; National High School Injury Registry 1989; Powell & Barber-Foss 1999a; Yard et al. 2008). In these studies, the majority of injuries were minor (≤7 days, 44–68%), followed by moderate (8–21 days, 17–29.1%) and major (>21 days, 6–27.1%). The NCAA ISS views injuries that resulted in ≥10 consecutive days of restricted or total loss of participation as severe. From 1988 to 2004, approximately 34% of match injuries and 28% of practice injuries restricted participation for ≥10 days (Agel et al. 2007).

Mean time loss per injury has also been reported in two prospective studies of high-school wrestlers. Pasque and Hewett (2000) reported a mean time loss per injury of 5 days, whereas McLain and Reynolds (1989) noted a mean time loss of 22.6 days. Several studies have cross-tabulated injury type with time loss to determine injury types associated with extensive time loss, including shoulder dislocations/subluxations (Yard et al. 2008), internal knee derangement (Agel et al. 2007), knee injury (Wroble et al. 1986), and fractures (Pasque & Hewett 2000; Yard et al. 2008).

Injury severity has also been measured by how often wrestlers required surgery for their injuries, with studies involving high-schools wrestler reporting a range of 2.35 to 7.8% (Requa & Garrick 1981; Hoffman & Powell 1990; Powell & Barber-Foss 1999a; Yard et al. 2008). Similarly, studies of college wrestlers report a range of 6.1% to 7.9% (NCAA 1998; Yard et al. 2008). Two studies, one involving high-school wrestlers (Powell & Barber-Foss 1999a) and the other involving intercollegiate wrestlers (Jarrett et al. 1998), reported the knee to be the most common anatomical location requiring surgery. Based on their study of lower-extremity injuries sustained by high-school athletes, Fernandez et al. (2007) reported wrestling as the sport with the highest percent of lower-extremity fractures requiring surgery (9.3%), followed by baseball (8.2%), girls' basketball (7.4%), and girls' soccer (7.3%).

Clinical Outcome

Recurrent Injury

The few studies that report on recurrent injury noted proportions ranging from 4.6% to 16.2% for high-school wrestlers (Patacsil 1955; Requa & Garrick 1981; Powell & Barber-Foss 1999a; Pasque & Hewett 2000) and 19% for college wrestlers (Patacsil 1955). Wroble et al. (1986) reported a 57% chance of reinjuring a knee in their study of collegiate wrestlers.

Catastrophic Injury

Catastrophic injuries are rare but tragic events in amateur, competitive wrestling. Much of the published literature on catastrophic injuries in wrestling exists in the form of case reports or case series (Wroble et al. 1986; Acigoz et al. 1990; Boden et al. 2002; Hewett et al. 2005). However, over the past 25 years, much of what we know about frequency and rate of catastrophic injury in wrestling has been provided by the National Center for Catastrophic Sports Injury Research (NCCSIR 2007). A total of 82 catastrophic high-school and college wrestling injuries, including 58 direct (injuries that resulted directly from participation in the skills of the sport) and 22 indirect (attributable to indirect causes, such as heart failure or weight-loss–related systemic failure) were reported to the NCCSIR between 1981 and 2007. During this period there were more than 6 million high-school participants (including 40,834 female participants) and 169,043 college male participants.

Almost all (78 of 82) catastrophic injuries involved-high school wrestlers. However, the rate per 100,000 participants for direct, nonfatal injuries was almost identical at the college and high-school levels (0.6 vs. 0.59 injury per 100,000 participants). The overall rate of direct catastrophic injuries including high-school and college wrestlers is estimated to be 1 per 100,000 participants. Kordi et al. (2008) reported 29 direct catastrophic injuries (12 fatalities, 11 nonfatal, and 6 serious) that occurred in wrestling clubs in Iran from July 1998 through June 2005. The injury rate was 1.99 direct catastrophic injuries per 100,000 wrestlers per year, which is higher than that reported for either high-school or college wrestlers in the United States.

Table 25.6 Percent comparison of injury types.

Study	Study Design	Level	No. of Subjects	No. of Injuries	Concussion	Contusion	Dislocation	Fracture
College								
Roy (1979)	R	C	115	332	0.3	17.2		1.5
Snook (1982)	R	C	90	129	1.1		20	4.4
Powell & Barber-Foss (1999a)	P	C		2,910				6.3
Agel et al. (2007)	R	C		3,097	10.2	3.3		
High School								
Garrick & Requa (1981)	P	HS	234	176				
First year						5.5		5.6
Second year						5.6		1.8
NHSIR (1989)	P	HS						7
Pasque & Hewett (2000)	P	HS	418	219		16.0	2.7	4.6
International								
Estwanik et al. (1978)	P	I	459	98		17.3		2

C = college; HS = high school; I = intermediate; NHSIR = National High School Injury Registry; P = prospective; R = retrospective.

Nonparticipation

An important area of sports injury research relates to how many injuries are season-ending injuries. During the 2006 U.S. junior freestyle and Greco-Roman wrestling tournament, 56% (43 of 77) of injured freestyle wrestlers and 50% (25 of 50) of injured Greco-Roman wrestlers discontinued participation in the tournament. Among the 418 high-school wrestlers studied by Pasque and Hewett (2000), 23 sustained season-ending injuries, with the most common involving the knee (44%) and shoulder (22%). Kersey and Rowan (1983) reported that six athletes were forced to withdraw from the 1980 NCAA wrestling championships because of injuries.

Residual Effects

Granhed & Morelli (1988) studied 32 former wrestlers, 39–62 years of age. Thirty-four percent (11 of 32) were found to have reduced spinal mobility, as compared with 5% (9 of 212) of controls ($P < 0.001$). Twenty-five percent of the wrestlers had old vertebral fractures that had healed but were still visible on radiographs and 25% (8 of 32) had pain during motion of the spine, as compared with only 6% (13 of 212) of the control group ($P < 0.001$).

Economic Cost

Knowles et al. (2007) estimated the economic cost of injuries over a 3-year period in a population of U.S. high-school varsity athletes representing 12 sports. Three types of cost were estimated: medical, human capital (medical costs plus loss of future earnings), and comprehensive (human capital costs plus quality of life). Wrestling had the highest mean medical cost per injury ($670), followed by football ($577). The mean human capital and comprehensive costs of wrestling injury were $2,080 and $10,212, respectively.

What Are the Risk Factors?

Although a considerable number of studies have provided data that are suggestive of relationships between risk factors and increased rate of injury, very few have tested risk factors for correlation or

Table 25.6 Percent comparison of injury types (continued)

Study	Infection	Laceration	Tendinitis/strain	Sprain	Bursitis	Meniscus	Neurotrauma	Metabolic Insults	Other
College									
Roy (1979)	16.9	3.6	19	23.8	1.2	1.8	2.1		12.3
Snook (1982)	16.7	3.3	3.3	42.2	1.1	3.3	1.1		3.3
Powell & Barber-Foss (1999a)			23.2	28.6			5.7		36.3
Agel et al. (2007)	39.6		31.9	38.8			11.1		68.4
High School									
Garrick & Requa (1981)									
First year		1.6	31.2	28					8
Second year		0	17.4	26.6					10.1
NHSIR (1989)			23	30			14		
Pasque & Hewett (2000)		4.1	30.6	22.8					19.2
International									
Estwanik et al. (1978)		11.2	10.2	42.8	4.1		3.1	8.2	

predictive value. Below is a discussion of risk factors that have been tested.

Intrinsic Factors

Age/Experience

Pasque and Hewett (2000) found, in a prospective study, that injured wrestlers had significantly more years of wrestling experience ($P < 0.001$) and were older ($P = 0.0019$) than uninjured wrestlers. Lorish et al. (1992) reported that the median age of injured wrestlers was significantly greater ($P < 0.001$) than the median age of the uninjured group.

Injury History

Becker et al. (1988) reported that wrestlers with a history of oral herpes simplex virus infection (cold sores) were less likely to report these skin infections than wrestlers without cold sores (RR, 0.25; 95% CI, 0.3–1.8). Schultz et al. (2004) reported that a history of concussion was associated with more than a twofold elevation of concussion rate in all athletes studied, including wrestlers.

Ligamentous Laxity

Pasque and Hewett (2000) reported that wrestlers with at least one positive test for ligamentous laxity had 50% fewer shoulder injuries than the comparison group ($P < 0.01$).

Weight

Lorish et al. (1992) reported an association between weight class and increased risk of injury ($P < 0.002$). However, this relationship did not persist in multivariate analysis ($P = 0.22$). Strauss and Lanese (1982) did not find any association between weight class and injury rates among high-school and college wrestlers during four wrestling tournaments.

Extrinsic Factors

Competitive Level

Yard et al. (2008) showed a marked increase in injuries per 1,000 AEs in college as compared with high-school wrestling (RR, 3.1; 95% CI, 2.7–3.6). Agel et al. (2007) reported that match injury rates were higher in more advanced NCAA divisions

($P < 0.01$). Strauss and Lanese (1982) reported a significantly higher rate for high-school wrestlers as compared with youth wrestlers when injuries were expressed per 100 matches. However, when injuries were expressed per 1,000 minutes, both youth and Big Ten wrestlers had significantly lower rates than for high-school wrestlers.

Anderson (2007) reported statistically significant differences in the rate of skin infections with class A (smaller schools; 2.5 cases per 100 wrestlers) as compared with class AAA (larger schools; 3.7 cases per 100 wrestlers) ($P = 0.008$). This finding awaits confirmation, however, by an analysis involving exposure-based injury rates, as the exposure (practice and competition time) may have been greater among the larger schools.

Wrestling Mats

Kohl et al. (2002) reported that mats stored open and flat were correlated with schools that had more ringworm infections ($P < 0.05$).

Wrestling Style

Yard and Comstock (2007) reported a significantly higher injury rate for freestyle as compared with Greco-Roman (RR, 1.51; 95% CI, 1.07–2.12). Thus, freestyle wrestling has an approximately 50% higher risk of injury than Greco-Roman wrestling. Lower-extremity injuries are almost exclusive to freestyle wrestling, probably because of the prohibition against lower-extremity involvement in the Greco-Roman style.

What Are the Inciting Events?

In any competitive wrestling situation, the wrestler engaged in offense seems less likely to be injured than the one engaged in defense (Laudermilk 1988; Boden et al. 2002; Grindstaff & Potach 2006). Since the object of the sport is to control one's opponent, the defensive wrestler, by definition, is more likely to be "out of control" and thereby less able to avoid being forced into risky body movements and positions. Requa and Garrick (1981) found that 85% of injuries that occurred when one wrestler clearly was in an advantageous position were sustained by the disadvantaged wrestler. However, the risk of injury in any given moment is a more complex construct than whether the wrestler is on "offense" or "defense."

Table 25.7 indicates that the majority of injuries sustained in college wrestling (18.3–74%) occurred during the takedown maneuver (Agel et al. 2007). Powell and Barber-Foss (1999a) reported that the takedown (see Figure 25.1) was also responsible for a large percentage of high-school wrestling injuries in both practice (64.4%) and competition (70%).

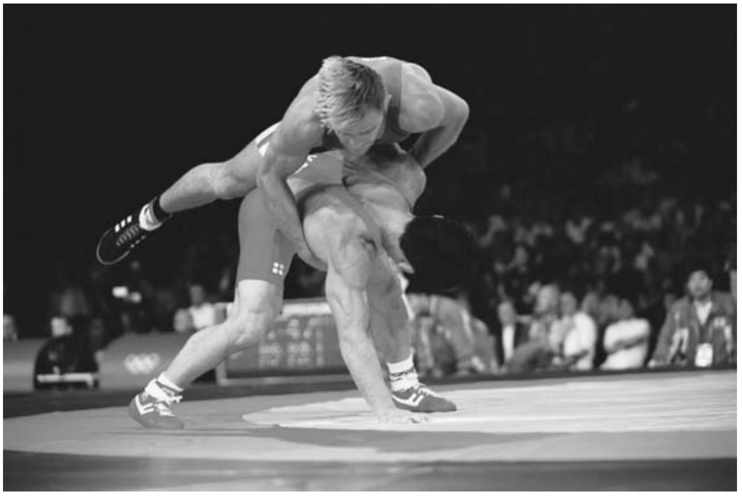

Figure 25.1 The takedown, where the defensive wrestler is out of control and being forcefully maneuvered, by the offensive wrestler, into an undesirable position is responsible for a large percentage of wrestling injuries. © IOC/Steve Munday.

Table 25.7 Distribution of injury by activity at the time of injury.

Activity at Time of Injury	Study Design	Takedown	Sparring	Escape	Near Fall	Reversal	Riding	Other
High School								
Yard et al. (2008)	P	39	14.7	9.3				
Pasque & Hewett (2000)	P	68		11			20[a]	1
Powell & Barber-Foss (1999)	P							
Practice		64.6						
Match		70						
Hoffman & Powell (1990)	P	44.1	10.5		12			
Estwanick & Rovere (1983)	P	50 (knee)						
Strauss & Lanese (1982)	P	42						51
Requa & Garrick (1981)	P	About 50		About 20				
Estwanick et al. (1980)		18.3 (overall); 68 (knee)						11.1 (overall)
College								
Yard et al. (2008)	P	41.9	27.1	4.7				
Agel et al. (2007)	R	42.3	13.9	7.1	4.3	4.2	12.9	15.3
Jarrett et al. (1998)	R	38	17	6		3	8	25
Wroble et al. (1986)		71						
Kersey & Rowan (1983)	P	24.5						75.5
Strauss & Lanese (1982)	P	58						27
High School and College								
Boden et al. (2002)		74		1				25

P = prospective; R = retrospective.
[a] Includes pinning.

Pasque and Hewett (2000) found that the majority of season-ending injuries occurred with the wrestler in the defensive takedown position. In Olympic wrestling, since most emphasis is on taking the opponent to the mat and less on maintaining control on the mat, takedowns are more common and the injury potential high. As shown in Table 25.7, after the takedown, sparring (10.5–27.1%), riding (8–20%), near fall (4.3–12%), and escapes (1–11%) are common inciting events in wrestling.

Several studies have provided information on injury mechanism, typically categorizing these as involving player contact (i.e., direct blow by opponent), other contact (i.e., with mat or bench), no contact (e.g., rotation around a planted hand or foot), and driven into mat (Jarrett et al. 1998; Agel et al. 2007; Yard & Comstock 2007). The college data indicate that player contact was the mechanism most associated with injury in both competition (55–64.4%) and practice (53.6–63.6%). In contrast, the national championship data reported by Yard and Comstock (2007) indicated that "driven into mat" was the mechanism most associated with injury, followed by "other contact" and "no contact." These authors also reported differences in injury mechanism depended on wrestling style. For example, driven into mat (54.8%) was the mechanism most frequently associated with injury in Greco-Roman wrestling while other contact (40.8%) was most frequent in free-style wrestling.

Injury Prevention

A detailed list of suggested preventive measures has been provided in two previous reviews of wrestling injuries (Wroble et al. 1996; Hewett et al. 2005). However, most of these recommendations emerged from clinical practice and descriptive research, and have not been tested to determine their effectiveness. Ethical, cost, and feasibility issues combine to preclude experimental research in wrestling. Weight-management programs and rules have evolved in wrestling to reduce the temptation to severely dehydrate to make weight. However, there are no quantitative data during the same period to suggest that improved nutrition and hydration have had an impact on injury rates.

There have been encouraging results in prevention studies for skin infections in wrestlers. Yard et al. (2008) provided data that support the early identification and quarantine of infected wrestlers to reduce skin infection. Anderson (2006) showed that prophylactic valacyclovir reduced herpes gladiatorum outbreaks by 87% at a wrestling camp as compared with previous years ($P < 0.01$). In an earlier, double-blind and open study, Anderson (1999) demonstrated that the use of 500 mg of valacyclovir daily suppressed recurrent outbreaks of herpes gladiatorum in wrestlers with a >2-year history of this condition. Finally, Strauss et al. (1989) provided evidence that replacing abrasive shirts with nonabrasive shirts reduced the incidence of herpes gladiatorum.

Several studies have researched whether equipment changes could reduce injuries. Beachy (2004) conducted a multisport study of intermediate and high-school athletes to determine the incidence and severity of dental injuries. The use of mouth guards was also documented. Female wrestlers incurred the highest rate of dental injury, but none of the injured athletes was wearing a mouth guard at the time of injury. Conversely, no dental injuries were reported in athletes wearing a mouth guard. Schuller et al. (1989) surveyed NCAA Division I wrestlers to assess attitudes and use of headgear and found a two-fold increased risk of auricular hematoma in wrestlers not wearing headgear. These results should be viewed with caution, however, because of the use of self-reports and nonrandom selection.

Further Research

Throughout this review, making comparisons between studies was problematic because of the varying study designs, study populations, and definitions of injury. Clearly, there is a need for a consensus statement on injury definitions and data-collection procedures in studies of wrestling injuries. In this regard, the published consensus statement for research in association football (soccer) may prove instructive (Fuller et al. 2006). Based on this review, the following are seen as important directions for further research relative to study design, the sport, and healthcare system.

Study Design

- Studies, in general, should be prospective in design with sufficient numbers of wrestlers to support risk-factor analyses. Studies should begin with accurate surveys of the injury history of participants.
- The definition of injury should be standardized. We recommend the current NCAA definition: "an injury [that] occurs during organized practice or competition *and* necessitates athletic trainer or physician [i.e., medical] attention *and* results in restriction from participation for one or more calendar days beyond the day of occurrence"
- Records should be kept using accurate coding of injury diagnosis according to a standard such as the International Classification of External Causes of Injury (ICECI) to facilitate statistical analysis.
- Studies of Olympic- or International-level wrestling are necessary to determine what is happening in that population. At present, only generalizations drawn from theoretically similar populations are available.
- Results should be expressed uniformly as injury rates per 1,000 AEs or, ideally, per 1,000 hours of practice or competition rather than as percentage of participants injured. However, there are significant logistical difficulties in accurately assessing hours of participation.
- Female wrestlers are due for serious study, defining their injury risk and risk factors, contrasting injury patterns with male wrestlers, and so forth.
- Studies should be both descriptive and analytical in nature. Descriptive research in need of further attention includes timing of injury, recurrent injury, nonparticipation, long-term effects of injury (e.g., cervical arthritis, heart disease, long-term effects of head injury, knee problems) and cost of wrestling injuries. Better data on specific injury types, such as traumatic brain injuries and catastrophic injuries are also needed.
- Analytical research, including analysis of both risk factors and preventive measures, are urgently needed. Risk factors of particular interest include injury history, joint flexibility, and strength, particularly the efficacy of neck-strengthening exercise on improving stability and reducing the risk of neck injury. Preventive studies need to address the relatively high incidence of upper-extremity fractures and knee injuries in college and high-school wrestling, respectively (Yard et al. 2008). The effectiveness of drills to simulate takedown technique, in controlled practice conditions, should also be explored (Yard et al. 2008).

The Sport

- Research should be done to define the forces involved in specific moves, holds, and throws by using modern, low-weight and size accelerometers in headgear and elsewhere, or the use of simultaneous multi-angle videography to study the kinesiology involved to gain a better understanding of inciting events might be achieved, resulting in more effective avoidance (e.g., by referee action during competition, by coach instruction during practice) of potentially dangerous situations.
- Prospective use of simultaneous multi-angle videography to routinely record matches would enable investigators to study matches in which injuries occurred, allowing more precise identification of causative or contributory factors (e.g., wrestler position, referee actions, illegal moves) This might also allow rules committees and officials' associations to refine concepts of what constitute potentially dangerous actions with the goal of encouraging earlier intervention by referees to stop such moves before they produce injury.
- The role of the referee and rules enforcement in injury prevention should better be defined. For example, "comment cards" listing possible factors that may have been operative in causing the injury for the official, coach or wrestler to check off after the incident, might be helpful in attempting to define factors that may have been active in causation. This would be best suited to tournament studies, for which considerable data can be collected in a short time.
- Investigate whether wrestling needs a system of coach qualification ratings and the relationship of coaching ability to injury.
- Further studies relating injury to equipment would be valuable. For example, Newton et al. (2002) looked at the interface between shoes and mat as a possible causative factor in knee injuries.

- Mat surfaces and composition have evolved considerably since the studies of the 1950s, in which mats were fabric covered and very difficult to clean (Konrad 1951). Newly designed or proposed surfaces can be tested for infection incidence, joint-injury incidence, surface friction, and ease of cleaning.

The Health Support System

- Research on the relative merits of soaps or disinfecting chemicals for preactivity and postactivity body cleansing in terms of reduction in skin infections.
- Available pharmaceuticals for suppression and prevention of spread of herpes gladiatorum have been well studied. As new agents become available they should be compared with the established agents through the use of randomized, controlled trials.
- Determine the value of all wrestlers being on continuous prophylaxis with antiviral agents during the entire season to stem the ever-increasing incidence of infection. What are the implications of this in terms of reactions to the pharmaceuticals, viral resistance development, and so forth?
- The concept of wrestlers being "noncompliant" with medical advice and injury care/rehabilitation is problematic. Does noncompliance complicate rehabilitation or independently render previously injured athletes more vulnerable to reinjury? To date, only Wroble et al. (1986) have attempted to study this issue in wrestlers.

References

Acigoz, B., Ozgen, T., Erbengi, A., Peker, S., Bertan, V. & Saglam, S. (1990) Wrestling causing paraplegia. *Paraplegia* **28,** 265–268.

Acksel, G.J. (1966) A study of interscholastic wrestling injuries in the state of Missouri during the 1965–66 season. Thesis, Eastern Illinois University, Charleston, IL.

Agel, J., Ransone, J., Dick, R., Oppliger, R. & Marshall S. (2007) Descriptive epidemiology of collegiate men's wrestling injuries: National Collegiate Athletic Association injury surveillance system 1988–1989 through 2003–2004. *Journal of Athletic Training* **42,** 303–310.

Anderson, B. (1999) The effectiveness of valacyclovir in preventing reactivation of herpes gladiatorum in wrestlers. *Clinical Journal of Sports Medicine* **9,** 86–90.

Anderson, B. (2003) The epidemiology and clinical analysis of several outbreaks of herpes gladiatorum. *Medicine and Science in Sports and Exercise* **35,** 1809–1814.

Anderson, B. (2006) Prophylactic valacyclovir to prevent outbreaks of primary herpes gladiatorum at a 28-day wrestling camp. *Japanese Journal of Infectious Disease* **59,** 6–9.

Anderson, B. (2007) Skin infections in Minnesota high school state tournament wrestlers: 1997–2006. *Clinical Journal of Sport Medicine* **17,** 478–480.

Beachy, G. (2004) Dental injuries in intermediate and high school athletes: a 15-year study at Punahou School. *Journal of Athletic Training* **39,** 310–315.

Beachy, G., Akau, C., Martinson, M. & Olderr, T. (1997) High school sports injuries; a longitudinal study at Punahou School: 1988 to 1996. *American Journal of Sports Medicine* **25,** 675–681

Becker, T., Kodsi, R., Bailey, P., Lee, F., Levandowski, R. & Nahmias, A. (1988) Grappling with herpes: herpes gladiatorum. *American Journal of Sports Medicine* **16,** 665–669.

Belongia E.A., Goodman J.L., Holland E.J., Andres C.N., Homann S.R., Manhanti R.L., Mizener, M.W., Erice A., & Osterholm, M.T. (1991) An outbreak of herpes gladiatorum at a high-school wrestling camp. *New England Journal of Medicine* **325,** 906–910.

Boden, B., Lin W., Young, M. & Mueller, F. (2002) Catastrophic injuries in wrestlers. *American Journal of Sports Medicine* **30,** 791–795.

Brown R.G. (1951) Nature and frequency of injuries occurring in Oregon high school interscholastic sports. Thesis, University of Oregon, Eugene, OR.

Caine, D., Caine, C. & Maffulli, N. (2006) Incidence and distribution of pediatric sport-related injuries. *Clinical Journal of Sports Medicine* **16,** 500–513.

Comstock, R., Knox, C., Yard, E. & Gilchrest, J. (2006) Sports-related injuries among high school athletes—United States, 2005–06 school year. *Morbidity and Mortality Weekly Report* **55,** 1037–1040.

Dane, S., Can, S., Gursoy, R. & Ezirmik, N. (2004) Sport injuries: relations to sex, sport, injured body region. *Perceptual and Motor Skills* **98,** 519–524.

de Loes, M. (1995) Epidemiology of sports injuries in the Swiss organization "youth and sports" 1987–1989. *International Journal of Sports Medicine* **16,** 134–138.

Emery, C., Meeuwisse, W. & McAllister, J. (2006) Survey of sport participation and sport injury in Calgary and area high schools. *Clinical Journal of Sports Medicine* **16,** 20–26.

Estwanik, J., Bergfeld, J. & Canty, T. (1978) Report of injuries sustained during the United States Olympic wrestling trials. *American Journal of Sports Medicine* **6,** 335–340.

Estwanik, J., Bergfeld, J., Collins, H. & Hall, R. (1980) Injuries in interscholastic wrestling. *Physician and Sportsmedicine* **8,** 111–121.

Estwanik, J. & Rovere, G. (1983) Wrestling injuries in North Carolina high schools. *Physician and Sportsmedicine* **11**(1), 100–108.

Fernandez, W., Yard, E. & Comstock, R. (2007) Epidemiology of lower extremity injuries among U.S. high school athletes. *Academic Emergency Medicine* **14,** 641–645.

Fuller C.W., Ekstrand J., Junge A., Andersen T.E., Bahr R., Dvorak J., Hagglund M., McCrory P., & Meeuwisse W.H. (2006). Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *British Journal of Sports Medicine* **40**, 193–201.

Garrick, J. & Requa, R. (1978) Injuries in high school sports. *Pediatrics* **61,** 465–469.

Garrick, J. & Requa, R. (1981) Medical care and injury surveillance in the high school setting. *Physician and Sportsmedicine* **9**(2), 115–120.

Granhed, H. & Morelli, B. (1988) Low back pain among retired wrestlers and heavyweight lifters. *American Journal of Sports Medicine* **16,** 530–533.

Grindstaff, T. & Potach, D. (2006) Prevention of common wrestling injuries. *Strength and Conditioning Journal* **28,** 20–28.

Hartmann, P.M. (1978) Injuries in preadolescent wrestlers. *Physician and Sportsmedicine* **6**(11), 79–82.

Hewett, T., Pasque, C., Heyl, R. & Wroble, R. (2005) Wrestling injuries. In: *Epidemiology of Pediatric Sports Injuries: Individual Sports.* (Caine, D.J. & Maffulli, N., eds.), Vol. 48 of *Medicine and Sport Science*, Xxxxx, Xxxxx, pp. 152–178.

Hoffman, H. & Powell, J. (1990) Analysis of NATA high school injury registry data on wrestling. *Athletic Training* **25,** 125.

Jackson, D.S., Furman, W.K. & Berson, B.L. (1980) Patterns of injuries sustained in intercollegiate athletes in two colleges over a two-year period. *Mount Sinai Journal of Medicine* **47**, 423–426.

Jarrett, G., Orwin, J. & Dick, R. (1998) Injuries in collegiate wrestling. *American Journal of Sports Medicine* **26,** 674–680.

Kersey, R. & Rowan, L. (1983) Injury account during the 1980 NCAA wrestling championships. *American Journal of Sports Medicine* **11,** 147–151.

Knowles, S.B., Marshall, S.W., Bowling, J.M., Loomis, D., Millikan, R., Yang, J., Weaver, N.L., Kalsbeek, W., & Mueller, F.O. (2006) A prospective study of injury incidence among North Carolina High School Athletes. *American Journal of Epidemiology* **164**,1209–1221.

Knowles, S.B., Marshall, S.W., Miller, T., Spicer, R., Bowling, J.M., Loomis, D., Millikan, R.W., Yang, J., & Mueller, F.O. (2007) Cost of injuries from a prospective cohort study of North Carolina high school athletes. *Injury Prevention* **13**, 416–421.

Kohl, T., Giesen, D., Moyer, J. & Lisney, M. (2002) Tinea gladiatorum: Pennsylvania's experience. *Clinical Journal of Sports Medicine* **12,** 165–171.

Konrad, I.J. (1951) A study of wrestling injuries in high school throughout seven Midwest states. Thesis, Michigan State College, Xxxxx, XX.

Kordi, R., Akbarnejad, A., & Wallace, A. (2008). Catastrophic injuries in the Olympic styles of wrestling in Iran. *British Journal of Sports Medicine.* July 4 [epub ahead of print]

Kraus, J. & Conroy, C. (1984) Mortality and morbidity from injuries in sports and recreation. *Annual Review of Public Health* **5,** 163–192.

Kvittem, B., Hardie, N., Roettger, M. & Conry, J. (1998) Incidence of orofacial injuries in high school sports. *Journal of Public Health Dentistry* **58,** 288–293.

Lian, O., Engebretsen, L. & Bahr, R. (2005) Prevalence of jumper's knee among elite athletes from different sports: a cross-sectional study. *American Journal of Sports Medicine* **33,** 561–567.

Lok, V. & Yuceturk, G. (1975) Injuries of wrestling. *Sports Medicine* **2,** 324–328.

Laudermilk, J. (1988) Catastrophic injuries in junior high and high school wrestling: a five season study. Master's thesis, University of North Carolina at Chapel Hill.

Lorish, T., Rizzo, T., Ilstrup, D. & Scott, S. (1992) Injuries in adolescent and preadolescent boys at two large wrestling tournaments. *American Journal of Sports Medicine* **20,** 199–202.

McGuine, T.A. (1989) Injury frequency during a one-day collegiate wrestling tournament. *Athletic Training* **24,** 227–229.

McLain, L. & Reynolds, S. (1989) Sports injuries in a high school. *Pediatrics* **84,** 446–450.

National Center for Catastrophic Sports Injury Research. (2008) URL http://www.unc.edu/depts/nccsi [accessed August 28, 2009]

National Collegiate Athletic Association Injury Surveillance System. (1993) *1992–1993 Wrestling Summary.* Shawnee Mission, KS.

National College Athletic Association. (1998) 1998–99 Sports Medicine Handbook, Overland Park, Kansas.

National Collegiate Athletic Association. (2008) *2007–08 Sports Medicine Handbook.* URL http://www.ncaapublications.com/ProductsDetailView.aspx?sku=MD08 [accessed September 15, 2008]

National High School Injury Registry, (1989) *Athletic Training* **23,** 383–388, **24,** 360–373.

Nelson, A., Collins, C., Yard, E., Fields, S., & Comstock, R. (2007) Ankle injuries among United States high school sports athletes, 2005–2006. *Journal of Athletic Training* **42**, 381–387.

Newton, R., Doan, B., Meese, M., Conroy, B., Black, K., Sebstianelli, W. & Kramer, W. (2002) Interaction of wrestling shoe and competition surface: effects on coefficient of friction with implications for injury. *Sports Biomechanics* **1,** 157–166.

Pasque, C. & Hewett, T. (2000) A prospective study of high school wrestling injuries. *American Journal of Sports Medicine* **28,** 509–515.

Patacsil, J. (1955). An analytical survey of the incidence of injuries sustained in intercollegiate and interscholastic wrestling. Thesis, Purdue University, Evanston, IL.

Porter, P. & Baughman, R. (1965) Epidemiology of herpes simplex among wrestlers. *Journal of the American Medical Association* **194,** 150–152.

Powell, J. (1981) National athletic injury/illness reporting system: eye injuries in college wrestling. *International Ophthalmology Clinics* **21,** 47–58.

Powell, J. & Barber-Foss, K. (1999a) Injury patterns in selected high school sports: a review of the 1995–1997 seasons. *Journal of Athletic Training* **34,** 277–284.

Powell, J. & Barber-Foss, K. (1999b) Traumatic brain injury in high school athletes. *Journal of the American Medical Association* **282,** 958–963.

Rechel, J.A, Yard, E.E, & Comstock, D.R. (2008) An epidemiologic comparison of high school sports injuries sustained in practice and competition. *Journal of Athletic Training* **43,** 197–204

Requa, R. & Garrick, J. (1981) Injuries in interscholastic wrestling. *Physician and Sportsmedicine* **9**(4), 44–51.

Roy, S. (1979) Intercollegiate wrestling injuries. *Physician and Sportsmedicine* **7**(11), 83–91.

Schuller, D., Dankle, S., Martin, M. & Strauss, R. (1989) Auricular injury and the use of headgear in wrestlers. *Archives of Otolaryngology and Head and Neck Surgery* **115,** 714–717.

Schulz, M., Marshall, S., Mueller, F., Yang, J., Weaver, N., Kalsbeek, W. & Bowling, M. (2004) Incidence and risk factors for concussion in high school athletes, North Carolina, 1996–1999. *American Journal of Epidemiology* **160,** 937–944.

Snook, G. (1982) Injuries in intercollegiate wrestling. *American Journal of Sports Medicine* **10,** 142–144.

Strauss, R.H. & Lanese, R.R. (1982) Injuries among wrestlers in high school and college tournaments. *Journal of the American Medical Association* **248,** 2016–2019.

Strauss, R.H., Leizman, D.J., Lanese, R.R. & Para, M.F. (1989). Abrasive shirts may contribute to herpes gladiatorum among wrestlers. *New England Journal of Medicine* **320,** 598–599.

Wroble, R. & Albright, J. (1986) Neck and low back injuries in wrestling. *Clinics in Sports Medicine* **5,** 295–325.

Wroble, R. (1996) Wrestling. In: *Epidemiology of Sports Injuries* (Caine, D., Caine, C. & Lindner, K., eds.), Human Kinetics, Champaign, IL, pp. 417–438.

Wroble, R., Mysnyk, M., Foster, D. & Albright, J. (1986) Patterns of knee injuries in wrestling: a six year study. *American Journal of Sports Medicine* **14,** 55–66.

Yard, E.E. & Comstock, R.D. (2007) A comparison of pediatric freestyle and Greco-Roman wrestling injuries sustained during a 2006 U.S. national tournament. *Scandinavian Journal of Medicine and Science in Sports,* **18**, 491–497.

Yard E.E., Collins C.L., Dick R.W. & Comstock R.D. (2008) An epidemiologic comparison of high school and college wrestling injuries. *American Journal of Sports Medicine* **36,** 57–64.

Zaricznyj, B., Lola J.M., Shattuck, M.A., Terrill, A.M., Robertson, R.V. & Gabrielle, D (1980) Sports-related injuries in school-aged children. *American Journal of Sports Medicine* **8**, 318–324.

PART 2

WINTER SPORTS

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Chapter 26

Alpine Skiing

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Introduction

Rock carvings from 4,000 years ago indicate that skiing was already established at that time. Skis have also been found in Scandinavia dating back 4,000 to 5,000 years. It is believed that the first use of skis was for hunting across snow-covered terrain as a means of transportation. Skis were also used for military operations. The first written instruction of skiing technique was published in a manual for the Norwegian army in 1765 (Vaage 1979).

Alpine skiing evolved from cross country skiing. Sondre Norheim from Morgedal, Telemark (Norway) is said to be the father of modern skiing. In the late 1830s, he was the first to use bindings around the heel and slightly carved skies to perform Telemark turns while descending the slopes. The sport of skiing further developed in Europe into what we today know as the Alpine technique with skiing between gates. The term *Alpine skiing* is named for the Alps.

The first Alpine skiing competition, a primitive downhill event, was held in Tromsø, Norway, in 1843 and thereafter, the sport spread to the remainder of Europe and the United States. According to the International Ski Federation (FIS), the first slalom race was organized in Mürren, Switzerland, in 1922. The Alpine skiing events became part of the Olympic program in 1936 in Garmisch-Partenkirchen with men's and women's slalom, downhill, and combined events. The giant slalom event became part of the Winter Olympics in Oslo, Norway, in 1952, while Super-G (super giant slalom) became part of the program in 1988. The Alpine events in the Olympics today are downhill (with the longest courses and highest speed), Super-G (combining the speed of downhill with the more precise turns of giant slalom), giant slalom (with fewer turns and wider, smoother turns than slalom), slalom (with the shortest course and the quickest turns), and combined (consisting of one downhill followed by two slalom runs) or super combined (consisting of just one single run of slalom and either a shortened downhill or a super-G run) (Olympic Movement 2007; The International Ski Federation (FIS) 2007).

Over time, skiing has gained popularity, and it is estimated that there are approximately 82 million Alpine skiers worldwide (Horterer 2005). Unfortunately, the sport of skiing is also associated with a risk of injuries. The risk of injuries has changed considerably as the sport and the equipment have evolved. Some studies, however, note that the rate of injury among recreational skiers stayed relatively constant for the last decade (Ekeland & Rødven 2009a; Laporte et al. 2009). This review of Alpine skiing injuries concentrates on the past decade of research studies, focusing on injury rates and types, measures to prevent skiing injuries, as well as possible directions for future research. The Alpine skiing injury literature published to date is based primarily on recreational skiers, with very few studies focusing on the competitive and elite level. Therefore, the review of injury incidence rates

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includes all studies, rather than those restricted to the most recent 10-year period.

Most studies of skiing injuries are descriptive; few have evaluated risk factors and injury prevention. Furthermore, there are several methodologic limitations that make interpretation and comparison between existing studies difficult. Injury definition varies across studies, with some studies not defining a skiing injury. Injury reporting varies, with studies based on self-report from skiers, on reports from ski patrols and physicians, and on hospital data. In addition, some studies are limited by small sample sizes or relatively short periods of data collection. Studies involving interviews may be compromised by recall bias. Lastly, studies vary in their methods for measuring exposure time.

Who Is Affected by Injury?

Incidence of Injury

The injury rate in skiing depends on injury definition, the reporting source, and exposure-time definition. Thus, rates of self-reported injury are much greater than those reported by ski patrols, followed by those reported by physicians and those reported using hospital data (Table 26.1). For calculating the injury-incidence rate for Alpine skiing, the number of injuries and the exposure time for the injured as well as the uninjured population on the slopes is essential. The injury rate (exposure-based) in skiing studies is reported based on injuries per 1,000 skier-days (SD) or skier-visits (SV) and mean days between injuries (MDBI). The literature is divided on whether to use the term SD or SV. As Lamont describes in his review from 1991 there is a subtle difference between the two approaches; a skier-day could be assumed to be the quantitative measure of the amount of skiing done, whereas a skier-visit simply denotes that a specific number of people visited the ski area (without accounting for the number of ski runs during that visit). The amount of skiing performed by individual skiers in a day is unknown and likely variable, so SV and SD are the same. MDBI is the total number of skier-days divided by the total number of the specific injury seen. It was introduced when injuries per 1,000 SD were divided into subgroups resulting in numbers less than one. Thus, 1 injury per 1,000 SD means 1,000 SD between injuries, and 5 injuries per 1,000 SD means 200 MDBI (Johnson et al. 1993). We have expressed injury rates as SD and MDBI as well as calculating SD.

The incidence rate of skiing injuries has varied significantly over the time period during which the sport developed. Incidence rates obtained from the Sun Valley experience, USA show that skiing injuries decreased from a rate of 7.6 injuries per 1,000 SD between 1952 and 1957 to 2.6 injuries per 1,000 SD between 1975 and 1976 (hospital- and physician-reported data) (Moritz 1959; Earle et al. 1962; Tapper 1978). Johnson et al. (1997) prospectively studied injures from a ski resort in Vermont and noted a decrease of 44% between 1972 when the injury rate was 4.7 injuries per 1,000 SD (227 MDBI) and 1994 when the injury rate was 2.5 injuries per 1,000 SD (405 MDBI). Thus, the injury rate for Alpine skiing has decreased dramatically during the past 40 years (Table 26.1).

Among elite skiers, Margreiter et al. reported in 1976 that 79% (31 of 40) of female racers and 87.8% (65 of 74) of male racers have had at least one serious injury during their career. Most of the serious injuries occurred during the downhill event. Injury rates for racing were 25 times greater than for practice. Raas (1982) reported in 1982 that 83% of 148 racers suffered injuries the previous 3 years. Two thirds of these injuries happened in downhill, as compared with 23% in slalom and 11% in giant slalom.

Participation Level

Injury rates for recreational skiers reported in prospective and retrospective injury studies during the past 10 years are shown in Table 26.2 and range from 1 to 3.7 injuries per 1,000 SD.

Only a few studies have evaluated injuries among competitive skiers during the different events for Alpine skiing. Two of these studies reported injury rates based on few injuries among participants from the downhill event—8.3 injuries per 1,000 runs among 15- to 19-year-old skiers in the Junior World Championship (Bergstrøm et al. 2001) and 1.1 per 1,000 runs for the downhill event in the 1994 Winter Olympic Games (Ekeland et al. 1996a).

Table 26.1 Change in injury rates over the past 40 years.

Study	Country	Design	Who Reported	Time Frame	Injury Rate (injuries/1,000 skier-days)
Haddon et al. (1962)	United States	P	Physician/medical students	1962	5.9
McAlister et al. (1965)	United States	R	Ski patrol	1965	7.3
Tapper & Moritz (1974)	United States	R	Hospital/outpatient clinic	1969–1972	5.1 in 1969–1970 3.2 in 1971–1972
Young et al. (1976)	United States	P	Ski patrol	1966–1973	4.2 in 1966–1967 2.8 in 1973–1974
Requa et al. (1977)	United States	R	Self report	1971–1973	9.3
Korbel & Zelcer (1982)	Australia	P	Ski patrol/ medical assistant	1980	1.4
Ascherl et al. (1982)	Germany	P	Hospital	1971–1981	2.4
Dubravcik et al. (1982)	Canada	P	Physician	1979–1981	2.7
Shealy (1985)	United States	P	Physician	1979–1981	2.16 in 1978–1979 2.2 in 1980–1981
Lystad (1989b)	Norway	P	Physician	1982–1986	0.9
Johnson et al. (1989)	United States	P	Physician	1972–1987	5 in 1971 2.5 in 1987
Sherry & Fenelon (1991)	Australia	R	Hospital	1988	3.22
Young & Lee (1991)	United States	P	Ski Patrol	1988–1989	3.37
Oliver & Allman (1991)	United States	R	Self report		24 (3.6 for those who were seen by ski patrol or physician)
Johnson et al. (1993)	United States	P	Physician	1972–1990	5 in 1973 2.5 in 1990
Shealy & Ettlinger (1996)	United States	P	Physician	1988–1990	2.2 in men 3.4 in women
Molinari et al. (1996)	Italy	R	Hospital	1988–1992	0.85
Warme et al. (1995)	United States	P	Physician	1982–1993	3.7
Langran et al. (1996)	Scotland	P	Physician	1993–1994	2.43
Jørgensen et al. (1998)	Denmark	R	Self-report	1995	33.6

P = prospective; R = retrospective.

Pujol et al. (2007) reported 8.5 anterior cruciate ligament (ACL) tears per 1,00 skier seasons. Ekeland and Holm (1985) followed competitive skiers for an entire season and reported 1.6 injuries per 1,000 racers, with the injury rate for the downhill events 10 times that for the slalom events.

Where Does Injury Occur?

Anatomical Location

A percentage comparison of injury location is shown in Table 26.3. Injuries to the lower extremity and knee were most frequent in all studies, followed by injuries to the upper extremity.

Head and Spine Injuries

Head injuries account for 9% to 19% of all Alpine skiing injuries (Table 26.3). The majority of head injuries are minor contusions and concussions (Lindsjö et al. 1985; Sulheim et al. 2006b). Sulheim et al. (2006b) reported that approximately 25% of the head injuries recorded by ski patrols were referred to a physician or hospital for further assessment or treatment, as these were potentially severe injuries.

Table 26.2 Injury rate for recreational skiers from the past 10 years reported by physicians, ski patrols, or hospitalization data.

Study	Study Design	Who Reported[a]	Data Collection	Control	Duration of Injury Surveillance	No. of Injuries	Participants	Injury Rate (MDBI ISD, ISV)
Johnson et al. (1997)	P	Physician	MR and Q	Yes, but not given total number	Season (1972–1994)	8023	Alpine (adults, >22 yr)	MDBI, 405; ISD, 2.5
Deibert et al. (1998)	P	Physician	MR	Yes (n = 40,000)	Season (1981–1994)	10162	Alpine (children, 1–10 yr; adolescents, 11–16 yr; adults, >16 yr)	ISD, 2.79 4.27 (children) 2.93 (adolescents) 2.69 (adults)
Bergstrøm et al. (1999)	P	Ski patrol	MR		Season (1990–1992)	183	Skiing	ISD, 1.8
Langran & Selvaraj (2002)	P	Physician	MR	Yes (n = 336)	Season (1999–2000)	732	674 (Alpine 67%)	Alpine: MDBI, 276; ISD, 3.7
Ekeland & Rødven (2000)	P	Ski patrol	MR		Season (1996–1998)	3915 (57% alpine)	Skiing	ISD, 1.2
Johnson et al. (2000)	P	Physician	MR and Q	Yes (n = 2,819)	Season (1972–1998)	15,526	Alpine	MDBI, 435; ISD, 2.3
Ronning et al. 2000	P	Hospital	MR	Yes, but total number not given	1997	55 injuries 35 Alpine injuries	Alpine	ISD, 1.2
Laporte et al. (2000)	P	Physician	MR	Yes, but total number not given	1992–1999	232,571	Alpine	MDBI, 400; ISD, 2.5
Dohjima et al. (2001)	P	Hospital	Q	No	10 seasons (1988–1997)	5,048	Skiing	ISV, 0.35
Greenwald et al. (2003)	P	Ski patrol and physician	MR	Yes	Season (1998–2000)	4,584 (65% Alpine)	Skiing	MDBI, 406 Alpine: MDBI, 456; ISD, 2.2
Made & Elmqvist (2004)	P	Physician	MR and Q	Yes but total number not given	1989–1999	1,775	Alpine	Uses other editors control material; ISD, 1
Ekeland et al. (2005)	P	Ski patrol	MR	Yes (n = 63% of 3,002)	2000–2002	6,402 (49% Alpine)	Alpine	ISD, 1.5 Alpine: ISD, 1.1

MDBI = mean no. of days between injuries; MR = medical record; n = number of uninjured Alpine skiers; P = prospective; Q = questionnaire; ISD = injuries per 1,000 skier-days; ISV = injuries per 1,000 skier-visits.

[a]Physician = physician assessments at mountain-based medical centers.

Table 26.3 Percent of injuries by body part.

		Davidson & Laliotis (1996) (n = 2,702)	Sutherland et al. (1996) (n = 396)	Boldrino & Furian (1999) (n = 160)	Goulet et al. (1999) (n = 41)	Langran & Selvaraj (2002) (n = 480)	Bridges et al. (2003) (n = 823)	Sulheim et al. (2006b) (n = 1,607)	Ekeland & Rødven (2009b) (n = 4,575)
		R	R	P	P	P	P	P	P
Head		9.2	Head/ neck/face,	14	Head/neck, 9.8	Head/face, 14.2	11	17.9	15
Skull			19						
Face		3.6					7		
Teeth		0.1							
Spine/Trunk				6					
Neck		1.2				1.5	2		3
Chest		1		4		1.9	Thorax and spine, 6		
Upper back	Back	2.9	Trunk/ back/ thigh, 8			2.9			7
Lower back									
Ribs		1							
Stomach/internal		4.6				1.3	1		Thorax/ abdomen, 3
Upper extremity		18.7	27	20	14.6	24.2	25		29
Clavicle		1.1					2		
Shoulder		7.2	Upper arm/ shoulder, 11	5		6.9	10		11
Arm		2.8				1	1		6
Elbow		0.5				1.5	2		
Forearm			Hand/ forearm 8						
Wrist		1.8				3.1	4		5
Hand/finger		5.3 (thumb, 4.2)	Thumb, 8	(9)		11.7 (thumb, 7.1)	Hand/ thumb		7

(*continued*)

Table 26.3 (*continued*)

	Davidson & Laliotis (1996) (n = 2,702)	Sutherland et al. (1996) (n = 396)	Boldrino & Furian (1999) (n = 160)	Goulet et al. (1999) (n = 41)	Langran & Selvaraj (2002) (n = 480)	Bridges et al. (2003) (n = 823)	Sulheim et al. (2006b) (n = 1,607)	Ekeland & Rødven (2009b) (n = 4,575)
						6		
Lower extremity	54.6	46	44	63.4	53.1	48		44
Hips	1.4							
Pelvis	0.1				1	5		
Thigh	0.2				3.3			4
Knee	37.3	32	(21)	24.4	36.7	30		24
Leg	9.3	Lower leg, 7	Lower leg, 13	26.8	Lower leg, 4.8	7		Lower leg, 10
Ankle	6.2	7		12.2	8.1	6		6
Foot/toe	0.1				0.2			
Other	1.7 Multiple, 1.4		Abdomen/ pelvis, 7	Trunk, 12.2				

n = no. of injuries; P = prospective study; R = retrospective study.

Spinal injuries account for 6% to 7% of all Alpine skiing injuries (Boldrino & Furian 1999; Ekeland & Rødven 2006; Johnson et al. 1997) and their frequency has remained constant during the past few decades. The most frequent type of spinal injuries requiring hospitalization are fractures located in the thoracolumbar spine (Reid & Saboe 1989; Tarazi et al. 1999). Burst fractures have been shown to be the most common fracture type (Tarazi et al. 1999).

Upper-Extremity Injuries

Injuries to the upper extremity account for 14% to 29% of all injuries in Alpine skiing (Table 26.3) and the most common injuries to the upper extremity are to the shoulder and thumb.

Injuries to the ulnar collateral ligament of the thumb account for between 4% and 10% of all skiing accidents (Davidson & Laliotis 1996; Johnson et al. 1997; Langran & Selvaraj 2002). These injuries are likely underreported by ski patrols and medical facilities because the skier may not seek medical attention at the ski area. A specific skiing injury, "skier's thumb," has been described as an acute injury to the first metacarpophalangeal joint, leading to instability of the joint (Mogan & Davis 1982; Lamont 1991). Carr et al. (1981) reported during the 1979–1980 season that the distribution of thumb sprains were 34.8% grade I, 47% grade II, and 18.2% grade III.

Shoulder injuries account for 5% to 11% of all injuries (Table 26.3). Men have twice as many shoulder injuries as women (Shealy & Ettlinger 1996; Ekeland & Rødven 2009b). The most common injuries are rotator cuff strains or tears, anterior glenohumoral dislocation, acromioclavicular separation and clavicular fractures (Kocher & Feagin 1996). The most common fracture (11%) in the shoulder area is to the clavicle, with the majority of these involving the middle third (Kocher & Feagin 1996). Radius fractures are not common among skiers (Davidson & Laliotis 1996). Over time, the decrease in the overall and lower-extremity injury rates has resulted in a proportionate increase in the ratio of upper-extremity to lower-extremity injuries. Warme et al. (1995) reported a decrease in the ratio of lower extremity to upper extremity injuries (from 4:1 in 1981–1982 to 2:1 in 1992–1993).

Lower-Extremity Injuries

In contrast to the upper extremity, the injury-incidence rate for the lower extremities has shown a significant decrease, and currently accounts for 44% to 63% of injuries in Alpine skiing (Table 26.3). The incidence rate for lower-extremity injuries has decreased 50% since the early 1970s (Johnson et al. 2000), with the greatest decrease (83%) in lower-leg injuries. This reduction is due to improvements in the design of release bindings and ski boots (Ettlinger & Johnson 1982; Hauser 1989; Deibert et al. 1998; Johnson et al. 1997; Ettlinger et al. 2006). In recent years, however, there has been little change in the injury rate from 1988 to 1998 (Johnson et al. 2000). During the Vermont skiing injury study (Johnson et al. 1997), the investigators noted a 90% decrease in twist-related injuries to the lower leg (below the knee) and an 83% decrease in bend-related injuries to the lower leg (tibia fractures). Ankle sprains, another component of the twist subgroup of lower-leg injuries, decreased by 92%. Lower-leg fractures currently account for 3% to 5% of all injuries (Ekeland et al. 2005; Langran & Selvaraj 2002).

Although the injury rate to the lower extremity has decreased significantly, mainly because of reduction of lower leg fractures and ankle sprains, the rate of severe knee sprains, usually involving the ACL has doubled from the 1970s to the 1990s (Johnson et al. 2000). During the last years there has been a moderate decrease in ACL injury rate (Johnson et al. 2009). ACL injuries account for 12% to 16% of all skiing injuries (Ellman et al. 1989; Johnson & Renström 1994; Warme et al. 1995; Laporte et al. 2000).

Knee sprains are the most common injury in Alpine skiing, accounting for approximately 25% to 30% of all injuries in adults. The most common sprains are medial collateral ligament injuries and ACL injuries, which had the same injury incidence rate in one study (Warme et al. 1995), but ACL injuries were more common in another study (Johnson & Renström 1994). For competitive skiers, knees also seem to be the most frequent body part injured, at 43%, whereas ACL injuries accounted for 31% of all injuries in Olympic skiers (Ekeland et al. 1997). A study by Pujol et al. (2007) among French national team Alpine racers followed from 1980 to 2005 reported an overall ACL injury rate of 8.5 per 100 skier-seasons.

One study in 1992 (Paletta et al. 1992) found acute ACL tears less likely to be accompanied by meniscal injuries while skiing as compared with other high-load athletic activities, but the incidence of isolated lateral meniscal injury was described to be higher in skiers than in nonskiers.

When Does Injury Occur?

Injury Onset

Alpine skiing is a sport with high demands regarding both speed and technical skills, especially for competitive skiers. Alpine skiing injuries tend to be acute-onset injuries related to specific traumatic incidents such as falls, jumps, and collisions with other skiers or obstacles such as trees, rocks, and lift bars. Injuries resulting from impact with T-bars or other equipment used on ski lifts account for about 5% of all skiing injuries (Lystad 1989b; Langran et al. 1996; Ekeland & Rødven 2006).

Chronometry

A study on injuries in top competition skiers in 1976 (Margreiter et al. 1976) noted that the risk of injury per kilometer skied was 25 times greater during a race than during practice. Ekeland et al. (1997) also found that among skiers competing at the 1994 Olympic Winter Games in Lillehammer, Norway, 60% of the injuries occurred during Alpine skiing competitions and 40% happened during training (Figure 26.1).

Little information is available on the time of year during which the injuries actually occur, but Pujol et al. (2007) described the injury rate to be greater during the winter competitive season and less during spring and summer in their study on elite French national skiers. This study evaluated only knee and ACL injuries and noted that these injuries occur when the athletes are on skis rather than while the athletes are training during the summer or spring.

Studies on recreational skiers reported that most injuries happen at the end of the skiing day, or just before the lunch break Oliver & Allman 1991; Zacharopoulos et al. 2009). This may indicate that tiredness is an important factor for skiing injuries. More injuries occur on the first skiing days of the season (Langran & Selvaraj 2002; Oliver & Allman 1991).

Figure 26.1 The frequency of Alpine skiing injuries is high. Copyright © IOC/Yo NAGAYA.

What Is the Outcome?

Injury Type

The most common types of skiing injuries are sprains (16–52%), contusions (14–36%), and lacerations and cuts (9–32%) (Lystad 1989b; Dohjima et al. 2001; Langran & Selvaraj 2002; Ekeland & Rødven 2009b). Fractures (13–23%) and dislocations (3–11%) are less commonly reported. The differences in distributions are likely due to different reporting methods from ski patrol, physicians, and hospital data.

Time Loss

According to Margreiter et al. (1976), 79.0% of female and 87.8% of male top-level skiers had sustained at least one severe injury during their career. A severe injury was defined as broken bones or injuries that affected the general health of a patient for >20 days. Another study, by Raas (1982), reported that 83% of the 30 top-ranked skiers for three Alpine events had sustained injuries severe enough to impair health and ability to work for >20 days. A study of Olympic Alpine racers (Ekeland et al. 1997) noted that as many as 72% had previously suffered a severe skiing injury (82% of the women and 57% of the men). These studies are limited by data that are decades old and the inclusion of few participants.

Clinical Outcome

Ekeland et al. (1997) reported that 30% of Olympic Alpine racers had suffered an ACL injury. One study also reported that the risk of an ACL injury was greater for the 30 top-ranked racers than athletes ranked lower (skiers at the national level) (Pujol et al. 2007). The same study, however, also revealed that it is possible to resume to skiing after serious knee injuries, because it did not seem to end the career of these top-ranked racers. Ekeland and Vikne (1995) have also shown that it is possible to regain the same World Cup ranking after serious injury when two or more ligaments in the knee have been injured.

ACL injury causes prolonged absence from work and sports and dramatically increases the risk of long-term sequelae such as abnormal joint dynamics and early onset of degenerative joint disease (Roos 2005). Although a massive research effort is ongoing to develop better treatment methods, we still lack evidence to suggest that reconstructive surgery of either menisci or cruciate ligaments decreases the rate of posttraumatic osteoarthritis (Myklebust & Bahr 2005). When assessing ACL follow-up studies of reconstructive surgery and nonoperative treatment, approximately half of these patients displayed signs of osteoarthritis after 10 years, and the extrapolation of these results indicates that the majority of patients will have osteoarthritis after 15 to 20 years (Myklebust & Bahr 2005).

A catastrophic injury is one that either is fatal or has extreme consequences for the patient, such as paralysis, irreversible loss of mental function, or loss of a limb. The incidence of catastrophic skiing injuries is shown in Table 26.4.

A multicenter review by Sherry and Clout (1988) described the skiing-related deaths over 32 years from the Snowy Mountains, Australia. The overall incidence of skiing-related deaths was 0.87 per million SD (MSD). For trauma-related deaths the incidence was 0.24 per MSD, for cardiac-related deaths 0.45 per MSD, and for hypothermia 0.18 per MSD. Berghold (1989) reported that between 1983 and 1986 the ratio of traumatic to non-traumatic deaths was 2:1. The traumatic deaths occurred at an age of 26 of 32 years (Shealy, et al. 2006; Sherry & Clout 1988; Xiang & Stallones 2003). Most severe injures in skiing reported from a trauma hospital (Furrer et al. 1995) were due to a fall at high speed or a collision with a fixed or mobile obstacle. Severe injuries in skiing should be considered as "high-energy trauma" and death following a skiing accident is nearly always due to a severe head or brain injury (Furrer et al. 1995).

Among a series of 11 skiers with spinal injuries, one third of the fractures resulted in paralysis and two thirds in an associated major injury of the extremities, thorax, abdomen, or head (Reid & Saboe 1989). Studies have shown that only 9% of skiers with spinal injuries required surgery for

Table 26.4 Incidence of catastrophic injuries.[a]

Study	What Kind of Injuries Reported	What Study Based	Duration	No. of Injuries	Injury Rate	Nation
Sherry & Clout (1988)	Deaths	Death certificate	1956–1987	29	0.87/MSD	Australia
Tarazi et al. (1999)	Serious spinal injuries[b]	Hospital	1994–1996	34	0.01/1,000 SD	United States
Shealy et al. (2000)	Deaths	NSAA (National Ski Areas Associations)	1991–1999	257	0.70/MSV	United States
Fukuda et al. (2001)	Head injuries	Hospital	1994–1999	442	1.03/100,000 SD	Japan
Xiang & Stallones (2003)	Deaths	Death certificate	1980–2001	274	0.53–1.88/MSV	United States

MSD = million skier-days; MSV = million skier-visits; SD = skier-days.
[a]All studies included here were retrospective.
[b] Fracture or neurologic deficit or both.

neurologic deficit or instability (Tarazi et al. 1999; Floyd 2001).

Economic Cost

Sports injuries have an economic impact on society, but the costs are difficult to estimate. The literature reflects this by virtue of there being few articles on the subject. The total socioeconomic cost for a severe knee injury, predominantly ACL injury, has been estimated to be 500,000 NOK (US$91,000) over the athlete's life span, including long-term disability, sick leave, and the possibility of additional surgical procedures (Prof Lars Engebretsen, University of Oslo, pers. comm.). A Finnish study from 1991 (Asikainen et al. 1991) stated the mean cost of treatment and sick leave among injured downhill skiers was FMK 5,500 (US$1,400) per patient. Shorter et al. (1996) found that patients ≤18 years of age admitted to a pediatric trauma center after skiing accidents had an average hospital stay of 7.3 days (range, 1–40) and an average cost of US$2,2000 (range, 900–151,000), exclusive of any prehospital or transport charges or charges incurred at other hospitals before transfer to a trauma center. Knee injuries alone represented 36% of the total costs but only 23% of all patients. Another study (de Loës et al. 2000) calculated the "mean cost per injury" of medical treatment by diagnosis and sport and noted that the overall costs for knee injuries was US$1,299 per injury for male and US$939 per injury for female downhill skiers.

What Are the Risk Factors?

Understanding the causes of injury is critical to advancing knowledge regarding injury prevention (Meeuwisse 1994). Sports-injury researchers must examine all the factors involved, including risk factors that explain why a particular athlete might be at risk in a given situation and injury mechanisms that explain how an injury occurs.

Intrinsic Factors

Sex

Study findings conflict regarding differences in risk of injury by sex among competitive skiers. Ekeland et al. (1996a) and Bergstrøm et al. (2001) described a significantly greater injury-incidence rate among female as compared with male competitive racers at the Winter Olympics in Lillehammer and a World Junior Championship. Ekeland & Holm (1985) reported no significant differences in injury by sex for Norwegian lower-level competitive skiers during the winter season of 1981–1982.

Regarding specific injury types, significant differences in ACL injuries have been reported for Olympic racers (Ekeland et al. 1996a), with 42% of female skiers reporting a previous ACL injury as compared with 10% of male skiers. A similar finding has been reported in competitive skiers in the United States, where female skiers were 3.1 times more likely to have sustained an ACL tear than their male counterparts (Stevenson et al. 1998). However, no significant differences were found in ACL injuries among female and male elite French national skiers (Pujol et al. 2007). In a cohort study of expert skiers (ski patrol and ski instructors), Viola et al. (1999) found no sex differences for ACL injuries during a 6-year period. From other sports that require pivoting movements, women are known to have a higher incidence of ACL injuries (Arendt & Dick 1995; Bjordal et al. 1997; Myklebust et al. 1998) and sex may be a factor related to knee injuries.

Some studies of recreational skiers have reported the total injury rate to be unrelated to sex (Davidson & Laliotis 1996; Ekeland et al. 2005). However, when looking at specific injury types, several studies have reported a twofold greater rate of knee injuries among women as compared with men (Greenwald et al. 1996; Shealy & Ettlinger 1996; Greenwald & Tolke 1997; Laporte et al. 2000; Ekeland et al. 2005; Ekeland & Rødven 2009b). In contrast, shoulder injuries, spine injuries, and head injuries have a significantly higher prevalence among men (Greenwald et al. 1996; Tarazi et al. 1999; Floyd 2001; Levy et al. 2002; Ekeland et al. 2005; Ekeland & Rødven 2009b). It is not clear whether differences in injury by sex are caused by anatomical differences or different skiing patterns.

Age

Among children, the injury rate is 4.27 injuries per 1,000 SD for 1-to-10-year-olds and 2.93 for adolescents 11 to 16 years old (Deibert et al. 1998). Ekeland et al. (2005) reported an injury incidence of 1.8 injuries per 1,000 SD for children <12 years of age, 2.3 for adolescents (13–19 years old), and 1.0 for adults (≥20 years old). The same pattern of adolescents having the greatest injury rate has also been reported in other studies (Cadman & Macnab 1996). Langran & Selvaraj (2002) evaluated Alpine skiing, snowboarding, and skiboarding and found that younger skiers (≤15 years) had an increased risk of injury (odds ratio, 1.9; 95% CI, 1.14-3.17). Among competitive Norwegian Alpine skiers, however, the incidence of injury was greater for athletes >16 years (3.8 injuries per 1,000 athletes) as compared with athletes <16 years of age (0.7) (Ekeland & Holm 1985).

Despite the decrease in tibial fractures among skiers due to improvements in ski-boot-binding systems, children have a much higher prevalence of lower-leg fractures than teenagers and adults (Ungerholm et al. 1985; Ekeland et al. 1993b; Deibert et al. 1998; Laporte et al. 2000; Ekeland et al. 2005). Ekeland et al. (1993a; 1993b) reported that fractures of the lower extremity were six to nine times more common in children <10 years of age than in adults. Skiers <10 years of age were found to have twice the risk of sustaining an equipment-related injury of the lower extremity as compared with older skiers. Ekeland & Rødven (2009b) reported the same age-related injury pattern, with a prevalence of lower-leg fractures of 13% for children <12 years of age as compared with a prevalence of 3% and 4% for teenagers and adults, respectively. Similar findings have been reported by others (Cadman & Macnab 1996; Molinari et al. 1996; Deibert et al. 1998). Children have weaker bones than adults and often ski on older bindings that are incorrectly adjusted (Ungerholm et al. 1985; Ekeland et al. 1993b).

Skiing Ability

Currently, there is no agreement in the literature on how to best classify skiing ability, but a classification based on the types of turns a skier could perform was better than a subjective classification of self-reported ability (Sulheim et al. 2006a). Skiers at the beginner level are at increased risk of injuries as compared with more experienced skiers (Haddon et al. 1962; Johnson et al. 1976; Shealy 1982; Lystad 1989b; Ekeland et al. 2005). A case–control study of lower-extremity equipment-related injuries reported that beginners had a sixfold increased risk of injury as compared with skiers with more advanced abilities (Ekeland et al. 1993b). Goulet et al. (1999) found that skiers with a low skill level were more likely to be injured as compared with highly skilled skiers (odds ratio, 7.54; 95% CI, 2.57–22.15). Langran & Selvaraj (2004) found that first-day participants in Alpine skiing had over twice as great a risk of injury as compared with the rest of the Alpine skiing population. In contrast, Boldrino & Furian (1999) described a tendency for the better skiers to be more at risk, although this study was based on injuries requiring hospitalization. Other hospital-record–based studies have shown the same pattern as studies using reporting by ski patrol and base lodge physician, with most injuries occurring among the beginner skiers (Dohjima et al. 2001). Among competitive skiers, those at the highest competitive level have been found to be at the greatest risk of injury (Pujol et al. 2007).

Psychosocial Characteristics

Studies of elite Alpine skiers have shown an increasing number of injuries in each succeeding third of the Alpine course, with most of the injuries (44–68%) occurring in the last third (Ekeland & Holm 1985; Ekeland et al. 1997; Margreiter et al. 1976). Alpine racers who were interviewed regarding the cause of their serious injury (time loss >20 days) described miscalculation, misjudgment, and fatigue as the most common causes (Margreiter et al. 1976; Raas 1982). The attitude and behavior of the skier may also be potential risk factors, with skiers overestimating their own ability and judgment. Some of these skiers may be classified as sensation seekers (Breivik 1999; Zuckerman 1979).

Extrinsic Factors

Weather Conditions

Although little information is available on weather as an injury risk factor, one study found that weather was not associated with skiing injury risk (Sandegård et al. 1991).

Equipment

Bindings

Bindings are designed to rigidly secure the skier's foot to the ski during skiing maneuvers. The most commonly used binding is the two-mode release system, in which the release occurs with a twisting motion (lateral motion at the toe) or a forward-leaning motion at the heel. Bindings termed "multirelease" release in other directions as well. Older multirelease bindings functioned poorly because of a high rate of inadvertent releases (Johnson & Renström 1994). Several international standards for binding releases have been developed, including the most commonly used International Standards Organisation (ISO) standard (which is based on the skier's weight and height, level of skill, age over 50, and length of ski-boot sole; Laporte et al. 2000), the weight standard used in the United States (American Society for Testing and Materials [ASTM]; Ettlinger et al. 2005), the tibial width method used in Germany (Deutsches Institut für Normung [DIN]; Delouche 1987), and a modified ISO stan-dard developed in France (AFNOR) with reduced adjustment values for women (Laporte et al. 2003).

The modern, well-adjusted release bindings have reduced the risk of lower-leg injuries (Johnson et al. 1974, 2000; Ekeland et al. 1993a, 2005; Hauser 1989; Ettlinger et al. 2006). In a fall, the risk of a lower-extremity injury is increased 2.3 times if one ski fails to release and 3.3 times if both skis remain attached (Bouter et al. 1989; Goulet et al. 1999). Goulet et al. (1999) found that 47% of skiers had incorrectly-adjusted release bindings, with children more likely to have incorrectly-adjusted bindings, and that those skiers were more likely to be injured than skiers with correctly-adjusted bindings (odds ratio, 2.11; 95% CI, 1.02–4.33). Johnson et al. (1974) introduced the term *lower-extremity equipment-related* (LEER) injuries, in which the injury occurred because the ski acted as a lever to bend or twist the leg, causing injury. Many LEER injuries are preventable with correctly-adjusted bindings.

In a review of ski-injury studies (Natri et al. 1999), virtually all found an association between knee injuries and the failure of the bindings to release. A retrospective survey (Urabe et al. 2002) of Alpine skiers with ACL injuries noted that 96% of the 80 respondents reported that their ski bindings did not release at the time of their injury. Unfortunately, the design of modern bindings cannot prevent the mechanism of this specific knee sprain (Ettlinger et al. 2006).

Skis

Comparing Alpine skiing to skiboard skiing highlights a difference in injury distribution. Skiboards or blades are short skis (<1 m in length) that have no release bindings and the MDBI for knee sprains was 5 times smaller for skiboarding than for Alpine skiing (Greenwald et al. 2003). Lower-leg fractures for skiboarders were, however, much more common, and the rate for tibial fractures was 3 to 8 times greater for skiboarding than for Alpine skiing (Greenwald et al. 2003; Langran 2005). Unlike conventional skis, skiboards do not have a long tail. The tail of the ski has been clearly implicated in the phantom foot mechanism (see description in the "ACL Injuries" section, below) that causes knee injuries for Alpine skiers. Thus, skiboarders rarely suffer ACL injuries (Langran 2005). However, it has been suggested that the lack of a release binding on most skiboards may explain the increased rate of tibial fractures in skiboarding (Greenwald et al. 2003).

The use of carving skis has not been shown to result in any significant difference in injuries as compared with traditional skis. In particular, the incidence of ACL ruptures is identical to that found with conventional skis (Laporte et al. 2000).

Goulet et al. (1999) found that skiers who rented ski equipment were much more likely to be injured than skiers who owned their equipment (odds ratio, 7.14; 95% CI, 2.59–19.87). So have Ekeland et al. (2005) found, but skiers who rented their equipment had a significantly lower skiing ability than those who skied on own equipment.

What Are the Inciting Events?

A complete description of the injury mechanism includes aspects of the injury situation, the athlete's behavior and movement, and the biomechanical characteristics of anatomical structures that sustain injury (Bahr & Krosshaug 2005). Most inciting events are based on presumptions from experts and self-reports from injured skiers. A more precise, detailed description of the inciting events based on video analysis combined with medical injury information are available for the most common skiing injuries (knee and ACL injuries).

ACL Injuries

Three common injury mechanisms for ACL injuries have been described (Jarvinen et al. 1994; Ettlinger et al. 1995; Johnson et al. 1997) (Figure 26.2). The valgus external lower-leg rotation mechanism (Figure 26.2a) occurs when the medial edge of the anterior/tip of the ski catches the snow and leads to a valgus external rotation trauma for the knee. The skier falls forward and the lower leg is abducted and externally rotated in relation to the thigh. In addition, the ski acts as a moment arm and magnifies the torque. This mechanism leads primarily to rupture of the medial collateral ligament, followed by the ACL, which is torn in approximately 20% of cases. These patients may also have bone contusions (Johnson 1988).

The "boot-induced anterior drawer" mechanism (Figure 26.2b) occurs when the skier lands on the tail of the ski, usually off balance posteriorly, with the knee fully extended and the contralateral arm rotated upward and rearward. The top of the ski boot forces the tibia forward, leading to a boot-induced anterior drawer maneuver (anterior directed force on tibia relative to the femur) that causes an isolated disruption of the ACL. This mechanism is common among freestyle and high-level Alpine skiers (Johnson & Pope 1977; Ettlinger et al. 1995; Natri et al. 1999).

The "phantom foot phenomenon" (Figure 26.2c) occurs when the skier is off balance to the rear and attempting to regain control, with the weight on the inside edge of the tail of the downhill ski and the uphill ski unweighted. The inside edge of the downhill ski catches the snow and drives the leg into forced internal rotation with the knee hyperflexed, resulting in an isolated ACL injury. The term *phantom foot* refers to the rear portion of the carved ski which engages the inner edge and cause the ski to turn producing the torque leading to the injury. This mechanism is believed to be the most common and insidious ACL scenario in Alpine skiing today and is the typical injury mechanism for recreational skiers.

Other mechanisms of ACL tears include hyperextension of the knee from a sudden deceleration or a combined loading mechanism with hyperflexion and weight on the tails of a skies with the ski tracking ahead, leading to a quadriceps eccentric contraction forcing the already stretched ACL to tear (McConkey 1986). Some investigators doubt whether a forceful quadriceps contraction can disrupt the ACL (Natri et al. 1999).

Anterior Shoulder Dislocation

The mechanisms for anterior shoulder dislocation are falls onto the shoulder (59%), falls onto the flexed elbow (20%), an external rotation/abduction torque applied to the arm when a ski pole is caught by the terrain (16%), and hyperextension of the shoulder (5%) (Kuriyama et al. 1984).

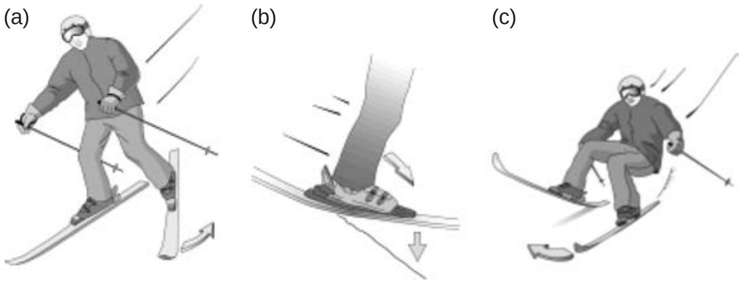

Figure 26.2 Three common injury mechanisms for ACL injuries: (a) valgus external rotation; (b) boot-induced anterior drawer; and (c) "phantom foot" mechanisms. Reproduced, with permission, from Koehle et al. (2002). Copyright 2008.

Skier's Thumb

One of the most common injuries to the upper extremities is an acute collateral ligament tear of the first metacarpophalangeal joint, or "skier's thumb." The typical mechanism involves a skier falling while holding a ski pole, forcing the thumb into adduction and extension (Browne et al. 1976).

Head Injuries

The mechanisms for head injuries are falls and collision (Fukuda et al. 2001; Levy et al. 2002; Hagel et al. 2005). Collisions with other skiers and snowboarders accounted for 58% and 34% of collision-related injuries; collisions with trees and lift towers for 4% and 3%, respectively; and collision with the edge of the ski for 1% (Levy et al. 2002). The primary cause of fatal injuries and the more serious head injuries is direct impact at high speed with trees (Levy et al. 2002; Lindsjö et al. 1985; Shealy et al. 2006; Xiang & Stallones 2003; Xiang et al. 2004) or a single fall at high speed (Furrer et al. 1995).

Spinal Injuries

A case series of 11 skiing-related spinal injuries noted that the skiers were injured when landing incorrectly from a jump out of control into trees (Reid & Saboe 1989).

Injury Prevention

Injury prevention is essential in making the sport of skiing as safe as possible. Unfortunately, little research is available on the effectiveness of strategies for preventing skiing injuries (Table 26.5). No research has evaluated injury prevention among competitive skiers. Injury-prevention strategies for skiers are related to the skier, the equipment, and slope-related factors (Ekeland et al. 2000a).

Skier-Related Strategies

Skiing Instruction and Skiing Experience

A randomized intervention study (Jørgensen et al. 1998) reported a 30% decrease in injury incidence in a group of Danish skiers who had viewed an instructional safety video on the way to a 1-week ski trip, as compared with a group of controls. The intervention group also demonstrated a significant behavioral effect for knee injuries when bindings had been tested and adjusted. A Scandinavian study reported that injury risk was less among skiers who had received skiing instruction as compared with those who had had no instruction (Ekeland et al. 1993a, 2005), but skiing experience had a greater impact on injury risk than skiing instruction. A study of ski-patrol members and ski instructors also showed that ACL injuries could be prevented if the skier learned to recognize the movements leading to this type of injury and learned an appropriate response, which included the correct falling technique to avoid injuries (Ettlinger et al. 1995).

Equipment-Related Factors

Helmets

The use of helmets and the potential impact on injury prevention has been studied in recent years. Sulheim et al. (2006b) found that using a helmet was associated with a 60% reduction in the risk for head injury (odds ratio, 0.40; 95% CI, 0.30–0.55; adjusted for other risk factors) when comparing skiers with head injuries with uninjured controls. Hagel et al. (2005) also found that wearing a helmet reduced the risk of head injury by 29% (adjusted odds ratio for helmet use in participants with head injury, 0.71; 95% CI, 0.55–0.92). Macnab et al. (2002) found among skiers and snowboarders under 13 years of age that those without helmets had an increased risk of head/neck/face injuries (relative risk, 2.24; 95% CI, 1.23–4.12) as compared with those who wore helmets. This study also found that helmet use was not associated with an increase in the incidence of cervical spine injuries, similar to findings by Ekeland et al. (2005).

Protective/crash helmets are compulsory for competitive skiers of all ages in competitions arranged by FIS. Strong evidence from the current published literature on helmet use for skiing

Table 26.5 Summary of studies examining effectiveness of injury-prevention strategies for Alpine skiing injuries.

Study	Study Design	Country	Time Frame	Participants (age)	Prevention Strategy	Injury Definition	Results
Jørgensen et al. (1998)	RCT	Denmark	1-wk ski trip	763 Danish skiers	1. Intervention: viewing an instructional safety video prior to a 1-week ski trip	All injuries	30% reduction of injuries in intervention group
Ettlinger et al. (1995)	Case–control	United States	One season (1993–1994)	On-slope staff from 20 ski areas and controls from 22	1. Intervention: training program involving viewing videotaped scenes in which knee injuries occurred 2. Control group	Serious knee sprain	ACL awareness training program was associated with a 62% decline in ACL injuries
Sulheim et al. (2006b)	Case–control, non-RCT	Norway	One season	3,277 injured skiers and snowboarders, 2,992 uninjured controls		Head injuries	Using a helmet was associated with a 60% reduction in the risk for head injury when comparing skiers with head injuries with uninjured controls
Hagel et al. (2005)	Case–control, non-RCT	United States	One season (2001–2002)	1,082 injured skiers and snowboarders, 3,295 uninjured controls		Head and neck injuries	Wearing a helmet reduce the risk of head injury with 29%
Macnab et al. (2002)	Case–control, non-RCT	Canada	One season (1998–1999)	1,517 injured skiers and snowboarders (157 head/neck/face, 70 <13 yr); 676 controls		Head/neck and face injuries	Children <13 yr of age without helmets had increased risk of head/neck/face injury, as compared with those who wore helmets
Hauser (1989)	RCT, P	Germany	Two seasons (1984–1986)	1,150 recreational skiers	1. Intervention group (n = 460) that had bindings tested and adjusted professionally during the 2-yr period 2. Control group (n = 690)	All injuries	The group of skiers who had their bindings correctly adjusted and controlled before the skiing season had only one third of the injuries of the control group
Bergstrøm et al. (2004)	Case study	Norway	Six seasons (1990–1996)	Skiers and snowboarders, 1,410 injury reports		All injuries	Better design and grooming of the slopes may reduce the risk of injury.
Ekeland et al. (1993a)	Case–control, non-RCT	Norway	One season (1985–1986)	341 injuries in 328 skiers; 316 controls		All injuries	Skiers who self-tested their bindings and had attended ski school classes had one third of the injury ratio for skiers who did neither.

P = prospective; RCT = randomized, controlled trial.

supports the recommendation for recreational skiers to wear helmets (Sulheim et al. 2006b).

Bindings

A self-release test for ski bindings has been implemented in Norway and Denmark, and studies have shown a significantly reduced risk of a ski injury in skiers who have tested their release bindings as compared to those who have not (Ekeland et al. 1993a; Jørgensen et al. 1998). The test is done by having the skier bend the knee, edging the inner side for the ski and slowly twisting the boot out of the toe portion of the binding. The heel is released by having the skier slowly lean forward (avoiding sudden jerks that may rupture the Achilles tendon; Ekeland et al. 2000a). The importance of a correctly adjusted self-release binding is especially important for children, because they are more likely to sustain lower-leg fractures than adult skiers. Hauser (1989) reported that a group of skiers who had their bindings correctly adjusted and tested before the skiing season had a 3.5 times smaller injury rate of lower-extremity injuries as compared with the control group. Finch and Kelsall (1998) critically reviewed studies examining the effectiveness of bindings and binding adjustment and suggested that currently used bindings are insufficient for the multidirectional release that is required to reduce the risk of serious knee injuries.

Slope-Related Factors

Groomed Slopes

Bergstrøm et al. (2004) evaluated the effect of trail design and the grooming of the slopes in their study of injury frequency and severity during a 5-year period. They reported that the injury rate and severity decreased with an improvement in safety measures on the slopes (i.e., better grooming, repair of rough sections, widening the slopes, and opening new slopes for beginners). One study also showed that the number of slopes was related to the lift capacity to prevent slope congestion and risk of collision injury (Lystad 1989a). The risk of injuries on ungroomed slopes are lower than for skiers on groomed slopes (Ekeland et al. 1996b), likely due to a greater skiing ability among powder skiers.

Further Research

Although it is not possible to prevent all injuries, the goal should be to try to reduce the injuries occurring in Alpine skiing and to make the sport as safe as possible. Studies of skiing injuries are limited by methodologic weaknesses, as previously noted, and it is important that future research include well-designed, prospective studies that can evaluate the injuries related to skiing. This is especially true for competitive skiing, in which current and reliable data on injury trends and patterns are lacking.

As sports develop and change over time, it is both necessary and important to have prospective, ongoing studies both to describe the injury risk and patterns as well as to identify potentially new and changing risk factors. As this review indicates, few injury risk factors have been statistically evaluated. Skiing exposure patterns are not well identified for injured and uninjured athletes; definitions of skiing exposure are also inconsistent between studies. Injuries result from a complex interaction of multiple risk factors, and it is therefore important for future studies to have a multivariate statistical approach, including both sufficient sample size and as many relevant risk factors as possible, as described by Bahr & Holme (2003).

Tapper & Moritz (1974) reported that ice, heavy, wet snow, large moguls, and flat light make skiing more difficult and increase the accident rate, but the magnitude of risk from these factors was difficult to quantify because they had no adequate controls. High-friction clothing has been suggested to reduce the risk of sliding accidents on icy slopes but rigorous analytic epidemiologic studies on this are lacking (Tapper & Moritz 1974). Ski goggles with special filters that improve visibility are helpful in unfavorable conditions (overcast skies, twilight, diffuse light, fog, snowfall) (Lingelbach & Jendrusch 2005), but intervention studies to support these findings are lacking and should be performed in the future.

Assessing specific injury mechanisms is of utmost importance. Additional studies are needed to provide more information about the high incidence of serious knee injuries. Current release bindings have altered injury patterns by reducing fractures to the lower leg and tibia but increasing the risk of knee injuries, especially ACL tears. Although some studies have demonstrated that injury-prevention measures have been effective, additional research of these injuries and their injury mechanisms is needed to provide information to assist with the development of better safety equipment.

Several studies have provided expert opinion that described prevention of skier's thumb by ensuring that the ski pole is released from the skier's hand before she or he hits the ground, through the use of poles without straps or the use of poles that protect the thumb (with a frontal bow) (Mogan & Davis 1982; Hauser 1989; Ekeland & Nordsletten 1994), but no rigorous epidemiologic studies have evaluated this potential prevention measure.

Prospective cohort studies that evaluate long-term follow-up on Alpine skiing injuries are also required, with particular attention to knee injuries. The FIS has established an Injury Surveillance System for all the disciplines within the FIS to assess injuries to elite racers by describing the injury patterns across multiple, successive seasons and to perform in-depth studies of injury mechanisms (Flørenes et al. 2007).

Another important goal for ski-injury research is to develop and use standard definitions in the skiing literature so that there is comparability within the sport as well as with other sports.

Lastly, the FIS has developed rules for safe skiing (The International Ski Federation (FIS) 2007). Although these are not evidence-based regulations, we find them important to mention because these rules have been used in litigation. If skiers fail to follow these rules, they can be subject to civil and criminal liability in the event of an accident.

References

Arendt, E. & Dick, R. (1995) Knee injury patterns among men and women in collegiate basketball and soccer: NCAA data and review of literature, *American Journal of Sports Medicine* **23**, 694–701.

Ascherl, R., Schlemmer, H., Lechner, F. & Bluemel, G. (1982) A ten year survey of skiing injuries. In: *Ski Trauma and Skiing Safety IV* (Hauser, W., Karlsson, J. & Magi, M., eds.), TUEV Edition, Technischer Überwachungs-Verein Bayern e. V., Munich, Germany, pp. 153–163.

Asikainen, P., Lüthje, P., Jarvinen, M., Avikainen, V. & Koskinen, I. (1991) Downhill skiing injuries and their cost at a Finnish skiing area, *Scandinavian Journal of Medicine and Science in Sports*, **1**, 228–231.

Bahr, R. & Holme, I. (2003) Risk factors for sports injuries—a methodological approach, *British Journal of Sports Medicine*, **37**, 384–392.

Bahr, R. & Krosshaug, T. (2005) Understanding injury mechanisms: a key component of preventing injuries in sport. *British Journal of Sports Medicine*, **39**, 324–329.

Berghold, F. (1989) Fatal skiing accidents in Austria—epidemiology and analysis. In: *Skiing Trauma and Safety: Seventh International Symposium, ASTM STP 1022*, (Johnson, R.J., Jr. Mote, C.D. & Binet, M.-H., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 63–68.

Bergstrøm, K.A., Askild, O., Jorgensen, N.A. & Ekeland, A. (1999) Evaluation of skiing injuries by Injury Severity Score. *Scandinavian Journal of Medicine and Science in Sports*, **9**, 110–113.

Bergstrøm, K.A., Bergstrøm, A. & Ekeland, A. (2001) Organisation of safety measures in an Alpine World Junior Championship. *British Journal of Sports Medicine*, **35**, 321–324.

Bergstrøm, K.A., Brandseth, K., Fretheim, S., Tvilde, K. & Ekeland, A. (2004) Back injuries and pain in adolescents attending a ski high school. *Knee Surgery, Sports Traumatology, Arthroscopy* **12**, 80–85.

Bjordal, J.M., Arnly, F., Hannestad, B. & Strand, T. (1997) Epidemiology of anterior cruciate ligament injuries in soccer. *American Journal of Sports Medicine* **25**, 341–345.

Boldrino, C. & Furian, G. (1999) Risk factors in skiing and snowboarding in Austria. In: *Skiing Trauma and Safety: Twelfth Volume, ASTM STP 1345* (Johnson, R.J., ed.), American Society for Testing and Materials, Philadelphia, PA, pp. 166–174.

Bouter, L.M., Knipschild, P.G. & Volovics, A. (1989) Binding function in relation to injury risk in downhill skiing, *American Journal of Sports Medicine* **17**, 226–233.

Breivik, G. (1999) *Sensation Seeking.* Norwegian School of Sport Sciences (Institutt for samfunnsfag), Oslo, Norway.

Bridges, E.J., Rouah, F. & Johnston, K.M. (2003) Snowblading injuries in Eastern Canada. *British Journal of Sports Medicine* **37**, 511–515.

Browne, E.Z., Jr., Dunn, H.K. & Snyder, C.C. (1976) Ski pole thumb injury. *Plastic and Reconstructive Surgery* **58**, 17–23.

Cadman, R. & Macnab, A.J. (1996) Age and gender: two epidemiological factors in skiing and snowboarding. In: *Skiing Trauma and Safety: Tenth Volume, ASTM STP 1266* (Mote C.D., Jr., et al.,

eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 58–65.
Carr, D., Johnson, R.J. & Pope, M.H. (1981) Upper extremity injuries in skiing. *American Journal of Sports Medicine* **9**, 378–383.
Davidson, T.M. & Laliotis, A.T. (1996) Alpine skiing injuries: a nine-year study. *Western Journal of Medicine* **164**, 310–314.
Deibert, M.C., Aronsson, D.D., Johnson, R.J., Ettlinger, C.F. & Shealy, J.E. (1998) Skiing injuries in children, adolescents, and adults. *Journal of Bone and Joint Surgery, American*, **80**, 25–32.
de Loës, M., Dahlstedt, L.J. & Thomee, R. (2000) A 7-year study on risks and costs of knee injuries in male and female youth participants in 12 sports. *Scandinavian Journal of Medicine and Science in Sports* **10**, 90–97.
Delouche, G. (1987) Bindings' release setting in Alpine skiing. In: *Skiing Trauma and Safety: Sixth International Symposium, ASTM STP 938* (Mote, C.D., Jr. & Johnson, R.J., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 202–211.
Dohjima, T., Sumi, Y., Ohno, T., Sumi, H. & Shimizu, K. (2001) The dangers of snowboarding: a 9-year prospective comparison of snowboarding and skiing injuries. *Acta Orthopaedica Scandinavica* **72**, 657–660.
Dubravcik, P., Szpilberg, M. & Maistrelli, G. (1982) Pattern of skiing injuries at Mont Tremblant—a changing dimension. In: *Ski Trauma and Skiing Safety IV* (Hauser, W., Karlsson, J. & Magi, M., eds.), TUEV Edition, Technischer Überwachungs-Verein Bayern e. V., Munich, Germany, pp. 171–177.
Earle, A.S., Moritz, J.R., Saviers, G.B. & Ball, J.D. (1962) Ski injuries. *Journal of the American Medical Association* **180**, 285–288.
Ekeland, A., Crockett, L.J. & Shamoo, A.E. (2000a) Skiing safety. In: *Skiing* (Ekeland, A., Crockett, L.J. & Shamoo, A.E., eds.), Harwood Academic Publishers, Newark, NJ, pp. 61–73.
Ekeland, A., Dimmen, S., Lystad, H. & Aune, A. K. (1996a) Completion rates and injuries in Alpine races during the 1994 Olympic Winter Games. *Scandinavian Journal of Medicine and Science in Sports* **6**, 287–290.
Ekeland, A. & Holm, A. (1985) Injury and race completion rates in Alpine competitions. In: *Skiing Trauma and Safety: Fifth International Symposium, ASTM STP 860* (Johnson, R.J. & Mote, C.D., Jr., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 293–301.
Ekeland, A., Holtmoen, A. & Lystad, H. (1993a) Lower extremity equipment-related injuries in Alpine recreational skiers. *American Journal of Sports Medicine*, **21**, 201–205.
Ekeland, A., Lystad, H., Holtmoen, A. & Nordsletten, L. (1996b) Injuries in powder skiing. *Scandinavian Journal of Medicine and Science in Sports*, **6**, 337–340.
Ekeland, A. & Nordsletten, L. (1994) Equipment related injuries in skiing: recommendations, *Sports Medicine*, **17**, 283–287.
Ekeland, A., Nordsletten, L., Lystad, H. & Holtmoen, Å. (1993b) Alpine skiing injuries in children. In: *Skiing Trauma and Safety: Ninth International Symposium, ASTM STP 1182* (R. J. Johnson, R.J., Mote, C.D., Jr. & Zelcer, J., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 43–49.
Ekeland, A., Nordsletten, L., Lystad, H. & Lereim, I. (1997) Previous skiing injuries in Alpine Olympic racers. In: *Skiing Trauma and Safety: Eleventh Volume, ASTM STP 1289*, (Mote, C.D., Jr. & Johnson, R.J., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 7–13.
Ekeland, A. & Rødven, A. (2000) Injuries in Alpine skiing, telemarking, and snowboarding. In: *Skiing Trauma and Safety: Thirteenth Volume, ASTM STP 1397* (Johnson, R.J., Zucco, P. & Shealy, J.E., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 87–94.
Ekeland, A. & Rødven, A. (2006) Injuries in Norwegian ski resorts 2002–2004. In: *Skiing Trauma and Safety: Sixteenth Volume, ASTM STP 1474,* (Johnson, R.J., Shealy, J.E. & Yamagishi, T., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 1–7.
Ekeland, A. & Rødven, A. (2009a) Injury trends in Norwegian ski resorts in the 10 year period 1996–2006. In: *Skiing Trauma and Safety: 17th Volume ASTM STP 1510* (Johnson, R.J., Shealy, J.E. & Langran, M., eds.) American Society for Testing and Materials, West Conshohocken, PA, pp. 31–38.
Ekeland, A. & Rødven, A. (2009b) Injuries in Norwegian ski resorts the winter seasons of 2005 and 2006. In*: Skiing Trauma and Safety: Seventeenth Volume, ASTM STP 1510* (Johnson, R.J., Shealy, J.E. & Langran, M., eds.), American Society for Testing and Materials, West Conshohocken, PA, pp. 43-48.
Ekeland, A., Sulheim, S. & Rødven, A. (2005) Injury rates and injury types in Alpine skiing, telemarking, and snowboarding. In: *Skiing Trauma and Safety: Fifteenth Volume, ASTM STP 1464,* (Johnson, R.J., Shealy, J.E. & Ahlbäumer, M.G., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 31–39.
Ekeland, A. & Vikne, J. (1995) Treatment of acute combined knee instabilities and subsequent sport performance. *Knee Surgery, Sports Traumatology, Arthroscopy* **3**, 180–183.
Ellman, B.R., Holmes, E.M., Jordan, J. & McCarty, P. (1989) Cruciate ligament injuries in female Alpine ski racers. In: *Skiing Trauma and Safety: Seventh International Symposium, ASTM STP 1022* (Johnson, R.J., Jr. Mote, C.D. & Binet, M.-H., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 105–111.
Ettlinger, C.F. & Johnson, R.J. (1982) The state of the art in preventing equipment-related Alpine ski injuries. *Clinics in Sports Medicine* **1**, 199–207.
Ettlinger, C.F., Johnson, R.J. & Shealy, J. (2006) Functional and release characteristics of Alpine ski. In: *Skiing Trauma and Safety 16th Volume, ASTM STP 1474* (Johnson, R.J. Shealy, J.E. & Yamagishi, T., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 65–74.
Ettlinger, C.F., Shealy, J & Johnson, R.J. (2005) Methods for improving the efficiency of alpine ski equipment rental operations. In: Skiing Trauma and Safety: Fifteenth Volume ASTM STP 1464 (Johnson, R.J., Shealy, J.E. & Ahlbäumer M.G., eds.), American Society for Testing and Materials, West Conshohocken, PA, pp13–22.
Ettlinger, C. F., Johnson, R. J. & Shealy, J. E. (1995) A method to help reduce the risk of serious knee sprains incurred in Alpine skiing. *American Journal of Sports Medicine*, **23**, 531–537.
Finch, C.F. & Kelsall, H.L. (1998) The effectiveness of ski bindings and their professional adjustment for preventing Alpine skiing injuries, *Sports Medicine* **25**, 407–416.
Flørenes, T.W., Nordsletten, N., Heir, S. & Bahr, R. (2007). The FIS Injury Surveillance System (FIS ISS). Presented at the 17th International Symposium on Ski Trauma and Skiing Safety, Aviemore, Scotland 13-19th May
Floyd, T. (2001) Alpine skiing, snowboarding, and spinal trauma,

Archives of Orthopaedic and Trauma Surgery **121**, 433–436.
Fukuda, O., Takaba, M., Saito, T. & Endo, S. (2001) Head injuries in snowboarders compared with head injuries in skiers. A prospective analysis of 1076 patients from 1994 to 1999 in Niigata, Japan. *American Journal of Sports Medicine* **29**, 437–440.
Furrer, M., Erhart, S., Frutiger, A., Bereiter, H., Leutenegger, A. & Ruedi, T. (1995) Severe skiing injuries: a retrospective analysis of 361 patients including mechanism of trauma, severity of injury, and mortality. *Journal of Trauma* **39**, 737–741.
Goulet, C., Regnier, G., Grimard, G., Valois, P. & Villeneuve, P. (1999) Risk factors associated with Alpine skiing injuries in children: a case-control study. *American Journal of Sports Medicine* **27**, 644–650.
Greenwald, R.M., France, E.P., Rosenberg, T.D. & Toelcke, T. (1996) Significant gender differences in Alpine skiing injuries: a five-year study. In: *Skiing Trauma and Safety: Tenth Volume, ASTM STP 1266* (Mote, C.D., Jr., et al., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 36–44.
Greenwald, R.M., Nesshoever, M. & Boynton, M.D. (2003) Ski injury epidemiology: a two year epidemiology study of injuries with skiboards. In: *Skiing Trauma and Safety: Fourteenth Volume, ASTM STP 1440* (Johnson, R., Lamont, M.K. & Shealy, J.E., eds.), pp. 113–120.
Greenwald, R.M. & Toelcke, T. (1997) Gender differences in Alpine skiing injuries: a profile of the knee-injured skier. In: *Skiing Trauma and Safety: Eleventh International Symposium, ASTM STP 1289* (Johnson, R.J., Mote, C.D., Jr. & Ekeland, A., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 111–121.
Haddon, W., Jr., Ellison, A.E. & Carroll, R.E. (1962) Skiing injuries: epidemiologic study. *Public Health Reports* **77**, 975–985.
Hagel, B.E., Pless, I.B., Goulet, C., Platt, R.W. & Robitaille, Y. (2005) Effectiveness of helmets in skiers and snowboarders: case-control and case crossover study. *British Medical Journal* **330**, 281.
Hauser, W. (1989) Experimental prospective skiing injury study. In: *Skiing Trauma and Safety: Seventh International Symposium, ASTM STP 1022* (Johnson, R.J., Mote, C.D., Jr. & Binet, M.-H., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 18–24.
Horterer, H. (2005) [Carving skiing]. *Orthopade* **34**, 426–432.
International Ski Federation (FIS). (2007) News/information—description of the FIS disciplines—Alpine skiing. URL http://www.fis-ski.com [accessed December 1, 2007]
Jarvinen, M., Natri, A., Laurila, S. & Kannus, P. (1994) Mechanisms of anterior cruciate ligament ruptures in skiing, *Knee Surgery, Sports Traumatology, Arthroscopy* **2**, 224–228.
Johnson, R.J. (1988) Prevention of cruciate ligament injuries. In: *The Cruciate Ligaments*, (Feagin, J.A., ed.), Churchill Livingstone, New York, pp. 349–356.
Johnson, R.J., Ettlinger, C.F. & Shealy, J.E. (1997) Skier injury trends—1972 to 1994. In: *Skiing Trauma and Safety: Eleventh Volume, ASTM STP 1289* (Johnson, R.J., Mote, C.D., Jr. & Ekeland, A., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 37–48.
Johnson, R.J., Ettlinger, C.F. & Shealy, J.E. (2009) Update on injury trends in Alpine skiing. In: *Skiing Trauma and Safety: Seventeenth Volume, ASTM STP 1510* (Johnson, R.J., Shealy, J.E. & Langran, M., eds.), American Society for Testing and Materials, West Conshohocken, PA, pp. 11–22.
Johnson, R.J., Ettlinger, C.F. & Shealy, J.E. (2000) Update on injury trends in Alpine skiing. In *Skiing Trauma and Safety: Thirteenth Volume, ASTM STP 1397* (Johnson, R.J., Zucco, P. & Shealy, J.E., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 108–118.
Johnson, R.J., Ettlinger, C.F. & Shealy, J.E. (1993) Skier injury trends—1972–1990. In: *Skiing Trauma and Safety: Ninth International Symposium, ASTM STP 1182* (Johnson, R.J., Mote, C.D., Jr. & Zelcer, J., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 11–22.
Johnson, R.J., Ettlinger, C.F. & Shealy, J.E. (1989) Skier injury trends. In: *Skiing Trauma and Safety: Seventh International Symposium* (Johnson, R.J., Mote, C.D., Jr. & Binet, M.-H., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 25–31.
Johnson, R.J. & Pope, M.H. (1977) Tibial shaft fractures in skiing. *American Journal of Sports Medicine* **5**, 49–62.
Johnson, R.J., Pope, M.H. & Ettlinger, C. (1974) Ski injuries and equipment function. *Journal of Sports Medicine* **2**, 299–307.
Johnson, R.J., Pope, M.H. & Ettlinger, C. (1976) The inter-relationship between ski accidents, the resultant injury, the skier's characteristics, and the ski boot binding system, *Orthopedic Clinics of North America* **7**, 11–12.
Johnson, R.J. & Renström, P.A.F.H. (1994) Injuries in Alpine skiing. In: *Clinical Practice of Sports Injury Prevention and Care* (Renström, P.A.F.H., ed.), Blackwell Scientific Publications, New York, pp. 676–698.
Jørgensen, U., Fredensborg, T., Haraszuk, J.P. & Crone, K.L. (1998) Reduction of injuries in downhill skiing by use of an instructional ski-video: a prospective randomised intervention study, *Knee Surgery, Sports Traumatology, Arthroscopy* **6**, 194–200.
Kocher, M.S. & Feagin, J.A., Jr. (1996) Shoulder injuries during Alpine skiing, *American Journal of Sports Medicine* **24**, 665–669.
Koehle, M.S., Lloyd-Smith, R. & Taunton, L.E. (2002) Alpine ski injuries and their prevention, Sports Medicine 32, 785–793
Korbel, P.J. & Zelcer, J. (1982) A controlled study of skiing injuries in Australia. In: *Ski Trauma and Skiing Safety IV* (Hauser, W., Karlsson, J. & Magi, M., eds.), TUEV Edition, Technischer Überwachungs-Verein Bayern e. V., Munich, Germany, pp. 178–183.
Kuriyama, S., Fujimaki, E., Katagiri, T. & Uemura, S. (1984) Anterior dislocation of the shoulder joint sustained through skiing: arthrographic findings and prognosis, *American Journal of Sports Medicine* **12**, 339–346.
Lamont, M.K. (1991) Ski injury statistics—what changes? In: *Skiing Trauma and Safety: Eighth International Symposium; ASTM STP 1104* (Mote, C.D. & Johnson, R., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 158–163.
Langran, M. (2005) Skiboard injuries—a three-year comparison with Alpine skiing. In: *Skiing Trauma and Safety: Fifteenth Volume ASTM STP 1464* (Johnson, R.J., Shealy, J.E. & Ahlbäumer, M.G., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 49–58.
Langran, M., Jachacy, G.B. & MacNeill, A. (1996) Ski injuries in Scotland: a review of statistics from Cairngorm ski area

winter 1993/94. *Scottish Medical Journal* **41**, 169–172.
Langran, M. & Selvaraj, S. (2002) Snow sports injuries in Scotland: a case-control study. *British Journal of Sports Medicine* **36**, 135–140.
Langran, M. & Selvaraj, S. (2004) Increased injury risk among first-day skiers, snowboarders, and skiboarders. *American Journal of Sports Medicine* **32**, 96–103.
Laporte, J.-D., Binet, M.-H. & Bally, A. (2003) Why the Ski Binding International Standards have been Modified in 2001. In: *Skiing Trauma and Safety: Fourteenth Volume, ASTM STP 1440* (Johnson, R.J., Lamont, M. & Shealy, J.E., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 64–94.
Laporte, J.-D., Binet, M.-H. & Constans, D. (2000) Evolution of ACL ruptures in French ski resorts 1992–1999. In: *Skiing Trauma and Safety: Thirteenth Volume, ASTM STP 1397* (Johnson, R.J., Zucco, P. & Shealy, J.E., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 95–107.
Laporte, J.-D., Binet, M.-H., Fenet, N., Constans, D & Joubert, J. (2009) Ski bindings and lower leg injuries, a case control study in Flaine, 2006. In: *Skiing Trauma and Safety: Seventeenth Volume, ASTM STP 1510* (Johnson, R.J., Shealy, J.E. & Langran, M., eds.), American Society for Testing and Materials, West Conshohocken, PA, pp. 77-88.
Levy, A.S., Hawkes, A.P., Hemminger, L.M. & Knight, S. (2002) An analysis of head injuries among skiers and snowboarders. *Journal of Trauma* **53**, 695–704.
Lindsjö, U., Hellquist, E., Engkvist, O. & Balkfors, B. (1985) Head Injuries in Alpine Skiing. In: *Skiing Trauma and Safety: Fifth International Symposium, ASTM STP 860,* (Johnson, R.J. & Mote, C.D., Jr., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 375–381.
Lingelbach, B. & Jendrusch, G. (2005) Contrast enhancing filters in ski sports. In: *Skiing Trauma and Safety: Fifteenth Volume, ASTM STP 1464* (Johnson, R.J., Shealy, J.E. & Ahlbäumer, M.G., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 23–30.
Lystad, H. (1989a) Collision injuries in Alpine skiing. In: *Skiing Trauma and Safety: Seventh International Symposium* (Johnson, R.J., Mote, C.D., Jr. & Binet, M.-H., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 69–74.
Lystad, H. (1989b) A five-year survey of skiing injuries in Hemsedal, Norway. In: *Skiing Trauma and Safety: Seventh International Symposium, ASTM STP 1022* (Johnson, R.J., Mote, C.D., Jr. & Binet, M.-H., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 32–40.
Macnab, A.J., Smith, T., Gagnon, F.A. & Macnab, M. (2002) Effect of helmet wear on the incidence of head/face and cervical spine injuries in young skiers and snowboarders. *Injury Prevention* **8**, 324–327.
Made, C. & Elmqvist, L.G. (2004) A 10-year study of snowboard injuries in Lapland Sweden, *Scandinavian Journal of Medicine and Science in Sports* **14**, 128–133.
Margreiter, R., Raas, E. & Lugger, L.J. (1976) The risk of injury in experienced Alpine skiers. *Orthopedic Clinics of North America* **7**, 51–54.
McAlister, R., Brody, J.A., Hammes, L.M., Feltz, E.T., Duncan, D.L. & Williams, M.L. (1965) Epidemiology of ski injuries in the Anchorage area. *Archives of Environmental Health* **10**, 910–914.
McConkey, J.P. (1986) Anterior cruciate ligament rupture in skiing: a new mechanism of injury. *American Journal of Sports Medicine* **14**, 160–164.
Meeuwisse, W.H. (1994) Assessing causation in sport injury: a multifactorial model. *Clinical Journal of Sport Medicine* **4**, 166–170.
Mogan, J.V. & Davis, P.H. (1982) Upper extremity injuries in skiing. *Clinics in Sports Medicine* **1**, 295–308.
Molinari, M., Bertoldi, L. & Zucco, P. (1996) Epidemiology of skiing injuries in a large Italian ski resort during 1988–1992. In: *Skiing Trauma and Safety: Tenth Volume, ASTM STP 1266* (Mote, C.D., Jr., et al., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 87–97.
Moritz, J.R. (1959) Ski injuries. *American Journal of Surgery* **98**, 493–505.
Myklebust, G. & Bahr, R. (2005) Return to play guidelines after anterior cruciate ligament surgery, *British Journal of Sports Medicine* **39**, 127–131.
Myklebust, G., Maehlum, S., Holm, I. & Bahr, R. (1998) A prospective cohort study of anterior cruciate ligament injuries in elite Norwegian team handball. *Scandinavian Journal of Medicine and Science in Sports* **8**, 149–153.
Natri, A., Beynnon, B.D., Ettlinger, C.F., Johnson, R.J. & Shealy, J.E. (1999) Alpine ski bindings and injuries: current findings. *Sports Medicine*, **28**, 35–48.
Oliver, B.C. & Allman, F.L. (1991) Alpine skiing injuries: an epidemiological study. In: *Skiing Trauma and Safety: Eighth International Symposium, ASTM STP 1104* (Mote, C.D., Jr., & Johnson, R.J., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 164–169.
Olympic Movement. (2007) Sports—skiing—Alpine skiing. URL http://www.olympic.org [accessed December 1, 2007]
Paletta, G.A., Jr., Levine, D.S., O'Brien, S.J., Wickiewicz, T.L. & Warren, R.F. (1992) Patterns of meniscal injury associated with acute anterior cruciate ligament injury in skiers. *American Journal of Sports Medicine* **20**, 542–547.
Pujol, N., Blanchi, M.P. & Chambat, P. (2007) The incidence of anterior cruciate ligament injuries among competitive Alpine skiers: a 25-year investigation. *American Journal of Sports Medicine* **35**, 1070–1074.
Raas, E. (1982) Some aspects of injuries in competitive skiers. In: *Ski Trauma and Skiing Safety IV*, (Hauser, W., Karlsson, J. & Magi, M., eds.), TUEV Edition, Technischer Überwachungs-Verein Bayern e. V., Munich, Germany, pp. 202–206.
Reid, D.C. & Saboe, L. (1989) Spine fractures in winter sports. *Sports Medicine* **7**, 393–399.
Requa, R.K., Toney, J.M. & Garrick, J.G. (1977) Parameters of injury reporting in skiing, *Medicine and Science in Sports* **9**, 185–190.
Ronning, R., Gerner, T. & Engebretsen, L. (2000) Risk of injury during Alpine and telemark skiing and snowboarding: the equipment-specific distance-correlated injury index. *American Journal of Sports Medicine* **28**, 506–508.
Roos, E.M. (2005) Joint injury causes knee osteoarthritis in young adults. *Current Opinion in Rheumatology* **17**, 195–200.
Sandegård, J., Eriksson, B. & Lundkvist, S. (1991) Nationwide Registration of Ski Injuries in Sweden. In: *Skiing Trauma and Safety: Eighth International Symposium, ASTM STP 1104* (Mote, C.D., Jr. & Johnson, R.J., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 170–176.
Shealy, J.E. (1982) Two year statistical analysis of skiing injuries at 13 selected

areas in the USA. In: *Ski Trauma and Skiing Safety IV* (Hauser, W., Karlsson, J. & Magi, M., eds.), TUEV-Edition, Munich, Germany, pp. 207–216.

Shealy, J.E. (1985) A comparison of downhill and cross-country skiing injuries. In: *Skiing Trauma and Safety: Fifth International Symposium, ASTM STP 860* (Johnson, R.J. & Mote, C.D., Jr., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 423–432.

Shealy, J.E. & Ettlinger, C.F. (1996) Gender-related injury patterns in skiing. In: *Skiing Trauma and Safety: Tenth Volume, ASTM STP 1266* (Mote, C.D., Jr., et al., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 45–57.

Shealy, J.E., Ettlinger, C.F. & Johnson, R.J. (2000) Rates and modalities of death in the U.S.: snowboarding and skiing differences—1991/92 through 1998/99. In: *Skiing Trauma and Safety: Thirteenth Volume, ASTM STP 1397* (Johnson, R.J., Zucco, P. & Shealy, J.E., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 132–138.

Shealy, J.E., Johnson, R.J. & Ettlinger, C.F. (2006) On piste fatalities in recreational snow sports in the US. In: *Skiing Trauma and Safety: Sixteenth Volume*, *ASTM STP1474* (Johnson, R.J. Shealy, J.E. & Yamagishi, T., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 27–34.

Sherry, E. & Clout, L. (1988) Deaths associated with skiing in Australia: a 32-year study of cases from the Snowy Mountains. *Medical Journal of Australia* **149**, 615–618.

Sherry, E. & Fenelon, L. (1991) Trends in skiing injury type and rates in Australia: a review of 22,261 injuries over 27 years in the Snowy Mountains. *Medical Journal of Australia* **155**, 513–515.

Shorter, N.A., Jensen, P.E., Harmon, B.J. & Mooney, D.P. (1996) Skiing injuries in children and adolescents. *Journal of Trauma* **40**, 997–1001.

Stevenson, H., Webster, J., Johnson, R. & Beynnon, B. (1998) Gender differences in knee injury epidemiology among competitive Alpine ski racers. *Iowa Orthopaedic Journal* **18**, 64–66.

Sulheim, S., Ekeland, A. & Bahr, R. (2006a) Self-estimation of ability among skiers and snowboarders in Alpine skiing resorts. *Knee Surgery, Sports Traumatology, Arthroscopy* **15,** 665–670.

Sulheim, S., Holme, I., Ekeland, A. & Bahr, R. (2006b) Helmet use and risk of head injuries in Alpine skiers and snowboarders. *Journal of the American Medical Association* **295**, 919–924.

Sutherland, A.G., Holmes, J.D. & Myers, S. (1996) Differing injury patterns in snowboarding and Alpine skiing. *Injury* **27**, 423–425.

Tapper, E.M. (1978) Ski injuries from 1939 to 1976: the Sun Valley experience. *American Journal of Sports Medicine* **6**, 114–121.

Tapper, E.M. & Moritz, J.R. (1974) Changing patterns in ski injuries. *Physician and Sportsmedicine* **2**, 39–47.

Tarazi, F., Dvorak, M.F. & Wing, P.C. (1999) Spinal injuries in skiers and snowboarders. *American Journal of Sports Medicine* **27**, 177–180.

Ungerholm, S., Gierup, J., Lindsjo, U. & Magnusson, A. (1985) Skiing injuries in children: lower leg fractures. *International Journal of Sports Medicine* **6**, 292–297.

Urabe, Y., Ochi, M., Onari, K. & Ikuta, Y. (2002) Anterior cruciate ligament injury in recreational Alpine skiers: analysis of mechanisms and strategy for prevention. *Journal of Orthopaedic Science* **7**, 1–5.

Vaage, J. (1979) Milepeler og merkedager gjennom 4000 år. In; *Skienes Verden*, Hjemmenes Forlag, Oslo, Norway.

Viola, R.W., Steadman, J.R., Mair, S.D., Briggs, K.K. & Sterett, W.I. (1999) Anterior cruciate ligament injury incidence among male and female professional Alpine skiers. *American Journal of Sports Medicine* **27**, 792–795.

Warme, W.J., Feagin, J.A., Jr., King, P., Lambert, K.L. & Cunningham, R.R. (1995) Ski injury statistics, 1982 to 1993, Jackson Hole Ski Resort. *American Journal of Sports Medicine* **23**, 597–600.

Xiang, H. & Stallones, L. (2003) Deaths associated with snow skiing in Colorado 1980–1981 to 2000–2001 ski seasons. *Injury* **34**, 892–896.

Xiang, H., Stallones, L. & Smith, G.A. (2004) Downhill skiing injury fatalities among children. *Injury Prevention* **10**, 99–102.

Young, L.R. & Lee, S.M. (1991) Alpine injury pattern at Waterville Valley—1989 update. In: *Skiing Trauma and Safety: Eighth International Symposium, ASTM STP 1104* (Mote, C.D., Jr. & Johnson, R.J., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 125–132.

Young, L.R., Oman, C.M., Crane, H., Emerton, A. & Heide, R. (1976) The etiology of ski injuries: an eight year study of the skier and his equipment. *Orthopedic Clinics of North America* **7**, 13–29.

Zacharopoulos, A.N., Tzanakakis, N.E. & Douka, M.I. (2009) Skiing and snowboarding injuries in Greece: a two-year case-control study. In: *Skiing Trauma and Safety: Seventeenth Volume, ASTM STP 1510* (Johnson, R.J., Shealy, J.E. & Langran, M., eds.), American Society for Testing and Materials, West Conshohocken, PA, pp. 23–30.

Zuckerman, M. (1979) *Sensation Seeking: Beyond the Optimal Level of Arousal*, Lawrence Erlbaum Associates, Hillsdale, NJ.

Chapter 27

Figure Skating

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Introduction

Athletes seek perfection in their sport and will drive themselves physically, mentally, and emotionally toward that goal despite the potential for injury. Skaters are such athletes. Figure skating is a sport wherein the skater as athlete and the skater as artist are a single embodiment, and they are scored for their achievements as both athlete and artist. According to 2007–2008 figures from the U.S. Figure Skating Association (2008), there were more than 196,000 skaters in U.S. clubs alone. Worldwide, the figures would surely be staggering.

Figure skating emerged during the 19th century as a popular recreational pastime with the development of steel blades and the addition of ballet and dance figures between 1850 and 1860. With the formation of the International Skating Union (ISU) in 1892 and their sponsorship of the first World Championships (men only), the evolution of serious figure skating competition began (International Olympic Committee 2008) and along with it, more risky moves and resulting injuries. In the 12 years that followed, the ISU officially added women's and pairs disciplines to the previously men-only competition, and in the 1908 Summer Games figure skating became an Olympic sport. There were no Olympics held in 1912 and 1916. However, the Games, including figure skating, resumed in 1920 following World War I, and the Winter Olympics were introduced in 1924.

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Men's, ladies, and pairs disciplines have been contested in every Winter Olympics since then, except for 1940 and 1944 because of World War II, and in 1976 ice dance was added. The newest discipline to be added is synchronized skating, or precision team skating. Sanctioned by the ISU in 2000 for world competition, synchronized skating became an Olympic medal event in 2008.

In 1990, a rule change eliminated school figures from competition, thus placing more emphasis than ever before on the athletic and technically demanding aspects of figure skating. Then in 2004, the judging system changed and began rewarding more difficult programs and giving partial credit for attempting to perform certain technically complex elements. The sport has now evolved so that competitors spend more time practicing multi-revolution and higher jumps, more daring lifts and throws (Figure 27.1), more intricate footwork and spin sequences, and more breathtaking feats showing flexibility. Whereas a single revolution in the air was adequate 100 years ago, today it is essential for every skater in singles disciplines to execute triple revolutions, if not quadruple revolutions for male skaters, in order to win the gold medal. In fact, it is considered advantageous to master triple jumps as early as 9 and 10 years old, before the body proportions change, despite the stresses placed on young growing bones (Pecina et al. 1990; Smith et al. 1991; Kujala et al. 1996; Smith 2000; Oleson et al. 2002; Dubravcic-Simunjak et al. 2003).

In a sport that began with men-only competition, it is interesting to note that today most figure skaters are female. Skaters usually begin lessons at

Figure 27.1 Xue Shen and Hongbo Zhao (CHN) during 2006 Winter Olympics in Torino. Pairs skaters spend more time practicing daring lifts and throws since the judging system changed in 2004 to reward athletic and technically demanding maneuvers. © IOC/ Yo NAGAYA

5 to 8 years of age. Training intensity increases by ages 8 to 10 to 2 to 3 hours on-ice and 1 hour off-ice daily, and increases again during adolescence to 2 to 4 hours on-ice and 1 to 3 hours off-ice daily. Female skaters usually peak competitively in their late teens or early 20s while male singles skaters often peak in their 20s (Smith 2000).

Against a background of increased difficulty of skills practiced at an early age and continued through the growth years, with the extreme intensity required, there is concern about a concomitant rise in the number of injuries affecting figure skaters. The purpose of this chapter is to provide an epidemiologic picture of injuries resulting from skating. Specifically, I will focus on competitive figure skating disciplines — singles skating, pairs skating, ice dancing, and synchronized, or precision team, skating.

There are numerous data on injuries in figure skating, and reducing them to common findings is not yet realistic, given the body of literature currently available. The studies are difficult to interpret and compare because of methodologic weaknesses such as small sample sizes in some studies, lack of uniform injury definitions, lack of uniform criteria for defining injury severity, too short a prospective data-collection period or too long a retrospective data-collection period, lack of homogeneity of research populations from study to study, and lack of controlled data-collection methods. Clearly, these limitations restrict the ability to generalize results across the skating population. Nevertheless, various properties and findings of the studies can allow reasonable inferences to be made about the epidemiology of injuries in figure skaters, and the ensuing sections of this chapter will illuminate those inferences.

Who Is Affected by Injury?

Table 27.1 shows the cohort studies from which figure skating injury rates or ratios were reported (Smith & Micheli 1982; Brown & McKeag 1987; Kjaer & Larsson 1992; Fortin & Roberts 2003) or in which adequate information was provided to allow calculation of an estimated rate or ratio by me (Brock & Striowski 1986; Smith & Ludington 1989; Dubravcic-Simunjak et al. 2003, 2006). Most of the data were collected retrospectively and therefore are subject to recall bias on the part of the skaters.

The rates indicate that figure skaters incur relatively few injuries, whether the rate is calculated as injuries per participant, injuries per 1,000 exposure hours, or injuries per year. Pairs skaters seem overwhelmingly to experience the highest frequency of injuries (0.32–1.83 injuries per participant), and male singles skaters (4.07 injuries per 1,000 exposure hours; 4.0 injuries per male participant) a higher frequency than female singles (0.15 injury per 1,000 exposure hours; 1.57 injuries per female participant), and female pairs (1.02 injuries per 1,000 exposure hours; 1.00 injury per female participant) a higher frequency than male pairs (0.03 injury per 1,000 exposure hours; 0.29 injury per male participant).

Table 27.1 Comparison of injury rates in figure skating before and after 1990 rule change.

Study	Design	Data Collection	Duration of Data Collection	No. of Injuries	Sample: No./Level	Sample: Age, yr	Rate
Singles, Pairs, Dance:							
Dubravcic-Simunjak et al. (2003)	R	Q (82% response)	3 Junior World Championships and 1 Croation Cup	373 total: M = 194 F = 179	469/junior: M = 233 F = 236	13–20 Median: M = 18 F = 16	0.80 injury per participant: M = 0.83 F =0 .76
				234 in singles 113 in pairs 26 in dance	211 singles 122 pair skaters 136 ice dancers		Injuries per discipline: 1.11 in singles 0.93 in pairs 0.19 in ice dance
Fortin & Roberts (2003)	R	Q	Entire figure-skating career	285: 119 in singles 110 in pairs 56 in dance	208/senior, junior, novice: 90 singles 60 pair skaters 58 ice dancers 104 seniors 80 juniors 24 novice		Retrospective data: 1.37 injuries per participant: 1.32 in singles 1.83 in pairs 0.97 in ice dance
	P	On-site evauation and treatment forms; evaluation, diagnosis, and treatment by medical team	1 USFSA national competition	55: 26 in singles 19 in pairs 10 in dance 35 in seniors 12 in juniors 8 in novice			Prospective data: 0.29 in singles 0.32 in pairs 0.17 in ice dance 0.25 in seniors 0.23 in juniors 0.33 in novice
Brock & Striowski (1986)	R	Q (93.75% response)	1 yr	28 total: M = 11 F = 17	60/senior & junior levels: M = 27 F = 33	Mean = 18.8	0.33 per 1,000 exposure-hr on-ice training[a] 0.27 per 1,000 exposure-hr on- and off-ice training[a] 0.46 injuries per participant: M = 0.41 F = 0.52

(*continued*)

Table 27.1 (*continued*)

Study	Design	Data Collection	Duration of Data Collection	No. of Injuries	Sample: No./Level	Sample: Age, yr	Rate
				 24 in seniors 4 in juniors 14 in singles 7 in pairs 7 in dance	 50 senior level 10 junior level 29 single skaters 13 pair skaters 18 ice dancers		Injuries per level: 0.48 senior 0.40 junior Injuries per discipline: 0.48 in singles 0.54 in pairs 0.39 in dance
Singles Skaters:							
Kjaer & Larsson (1992)	P	Weekly exam by physician	1 yr	18	8/elite: M = 3 F = 5		1.72 per 1,000 hr ice training 1.37 per 1,000 hr total training 2.25 injuries per participant
Singles, Pairs:							
Brown & McKeag[b] (1987)	R	Q (100%)	1 yr	48 total: 9 in pairs: M = 2 F = 7 39 in singles: M = 28 F = 11	14/mostly senior level: M = 7 F = 7	M = 15.2–21.6 (mean = 18.1) F = 12.8–16.0 (mean = 14.0)	0.35 per 1,000 exposure-hr 0.65 per 1,000 exposure-hr in pairs training: M = 0.03 per 1,000 exp-hr F = 1.02 2.83 per 1,000 exposure-hr in singles prior to pairs: M = 4.07 F = 0.15 3.42 injuries per participant 0.64 per participant in pairs M = 0.29 F = 1.00 2.79 per participant in singles prior to pairs: M = 4.00 F = 1.57
Smith & Micheli (1982)	R	Q and exam by medical team for anatomical malalignment, flexibility, and evidence of prior injury	Entire skating career	52 total: M = 19 F = 33	19/completed at least the third figure or silver pair test M = 4 F = 15	11–19 (mean = 13.8)	1.84 per 1,000 exposure-hr for serious[c] injuries only: 0.09 injury per seriously skated year per skater, or 0.12 per competitive year per skater 2.74 injuries per participant over entire skating career: M = 4.75 F = 2.20

Pairs, Dance:							
Smith & Ludington (1989)	P	Exam and treatment of injuries by medical team	9 mo competitive season	49 total:	M = 24, F = 24: 8 senior pairs 6 junior pairs 2 novice pairs 4 senior dance 4 junior dance	M = 13.2–27.9 (mean = 21.9± 3.7) F = 10.9–27.9 (mean [±SD] = 18.0±3.6)	0.90 per 1,000 exposure-hr 1.02 injuries per participant: 1.4 per sr. F pairs skater 0.4 per sr. M pairs skater 0.5 per jr. F pairs skater 0.8 per jr. M pairs skater 0.0 per nov. F pairs skater 0.0 per nov. male pairs skatr 1.2 per sr. F dance skater 1.0 per sr. male dance skater 0.5 per jr. F dance skater 0.0 per jr. M dance skater
				33 serious[d]: 12 in M 21 in F 22 in pairs 11 in dance 23 in seniors 10 in juniors 0 in novice			0.69 serious[d]/participant: 0.50 in M 0.88 in F 0.69 in pairs 0.69 in dance 0.72 in seniors 0.83 in juniors 0.00 in novice
				16 <serious[d]			0.33 <serious[d]/participant
Synchronized:							
Dubravcic-Simunjak et al. (2006)	R	Q (100% response)	Entire synchro skating career[e]	572 total: M = 19 F = 553 Acute: 412 148 pre-2000 264 post-2000	528/senior: M = 14 F = 514	15-32 M = 18–32 (mean = 22.2) F = 15–28 (mean = 19.4)	1.08 injuries per participant: M = 1.36 F = 1.08 0.78 acute injury per participant 0.28 pre-2000 acute injury 0.50 post-2000 acute injury

Where no figures are reported, data were not available within the publication or calculations were not possible from the available data.
F = female; I = interview; M = male; P = prospective; R = retrospective; Q = questionnaire; USFSA = U.S. Figure Skating Association.
[a] This rate is based on *average* exposures for the groups (e.g., singles, pairs, dancers); specific hours per skater or group were not provided.
[b] Brown and McKeag collected data on pairs skaters and included injuries on the participants during their singles training prior to becoming pairs skaters.
[c] "Serious" injuries were defined as causing the skater to cease or markedly limit training for ⩾7 consecutive days.
[d] "Serious" injuries were defined as disabling the skater from all practice for ⩾7 consecutive days of missed or markedly limited normal training. "Less serious" injuries were defined as either causing markedly limited training for <7 days, or causing minor changes in training for ⩾4 weeks.
[e] Some data were stratified according to time of occurrence before or after the year 2000, when the sport of synchronized figure skating became an International Skating Union–sanctioned event.

Rates between sexes and among competitive levels vary widely, making comparisons difficult.

Only one study on synchronized figure skating resulted from the literature search. Dubravcic-Simunjak et al. (2006) reported 1.08 injury per participant based on data collected retrospectively from 528 synchronized skaters. They were able to divide data into pre-2000 and post-2000 sets, as the year 2000 marked the beginning of world competition. They found an increase in acute injuries per participant from 0.28 before 2000 to 0.50 after 2000. They cautiously suggest that the demands placed on synchronized skaters in the four years since the inception of world competition may have contributed to the increase.

Where Does Injury Occur?

Anatomical Location

Percent comparisons of anatomical locations of figure skating injuries, by gender and skating discipline, are shown in Table 27.2. What is immediately noticeable is the predominance, with few exceptions, of lower extremity injuries across studies (33.3–100.0%). There is also an indication that certain injury locations are more dominant in specific portions of the skating population. Among singles skaters, female skaters seem to incur slightly more lower extremity injuries (70.9–85.7%) than male skaters (59.9–82.6%). Noticeably, there seem to be almost no injuries to male pairs skaters (n = 7) in Brown and McKeag's (1987) study, and those two injuries were to the head, and not the lower extremity. Lower extremity injuries were also less frequent in a study by Smith and Ludington (1989), who stratified 48 injuries into serious (requiring ⩾7 days recovery time) and less serious (requiring <7 days recovery time) injuries instead of by sex, and therefore are not included in the table. They found that almost one third of serious injuries in pairs skaters were to the head, trunk, and upper extremity, most resulting from lifts. By contrast, 90% of serious injuries to ice dancers took place in the lower extremity. As usual, these findings should be considered cautiously because of the limitations of the various studies.

Although lower extremity injuries usually ranked either first or second in frequency among the studies in Table 27.2, low back injuries (3.6–33.3%) or pain usually ranked third or fourth in frequency. However, Fortin and Roberts (2003) reported that low back injuries ranked first among male singles skaters (26.7%) in their brief prospective study. It has been suggested that low back injuries or pain may be brought on by microtrauma associated with a greater emphasis on jumping practice and daring lifts and their creative entrances and exits (Smith & Micheli 1982; Brock & Striowski 1986; Kujala et al. 1996; Dubravcic-Simunjak et al. 2003; Fortin & Roberts 2003).

It is difficult to ignore the high frequency of head and upper extremity injuries in pairs (9.1–100.0%), dance (5.6–20.0%), and synchronized skaters (10.5–14.2%). Dubravcic-Simunjak et al. (2006) reported that 81 (14.2%) of 572 injuries were to the head in synchronized skating, pointing out that 69 of them happened in the last four skating seasons of data collection (2000 through 2004). This may suggest that increased demands of the sport since its first world competition in 2000 and its highly creative team maneuvers and lifts may be causing some of the reported concussions, contusions, hematomas, and lacerations, but this would be speculation at this time.

Environmental Location

Injuries during on-ice practice are overwhelmingly predominant, at 55.6–94.9% (Brock & Striowski 1986; Smith & Ludington,1989; Pecina et al. 1990; Fortin & Roberts 2003; Dubravcic-Simunjak et al. 2006). This is not surprising, given that practice requires more hours than competition, thus resulting in more exposure hours to risk of injury. However, these percentages should not be confused with injury rates. If we were able to calculate the risk of injury from these data, we may find a greater risk of injury during competition than during practice, as has been found in gymnastics, for example (Caine & Nassar 2005).

Smith & Ludington (1989) also reported that 65.3% of injuries incurred during on-ice practice were serious (requiring ⩾7 consecutive days of missed or markedly limited normal training) and 28.6% were less serious (causing <7 days of markedly limited training, or causing minor changes in training for ⩾4 weeks).

In synchronized skating (Dubravcic-Simunjak et al. 2006), on-ice practice accounted for 338 (82%) of 412 acute injuries, of which 91 (26.9%) took place during individual practice and 247 (73.1%) occurred during team practice. Only 74 (17.9%) of the 412 acute injuries occurred during off-ice practice or training.

Injuries may also relate to geographic location — for example, climatic conditions (cold or warm, moist or dry), elevation, terrain, ice, snow, water, land, and air quality. Cold air and possibly pollution from ice-resurfacing equipment can cause pulmonary responses that induce bronchospasm or asthma. In one retrospective and one prospective study with controls, the incidence of exercise-induced bronchospasm in figure skaters was found to be 24% to 35% (Mannix et al. 1996a; Weiler & Ryan 2000), suggesting that intensive exercise coupled with the cold environment may be responsible for causing injury to the airways. Furthermore, Weiler and Ryan (2000) reported that more female athletes (35.4%) than male athletes (13.2%) at the 1998 Winter Olympics had asthma.

When Does Injury Occur?

Injury Onset

As shown in Table 27.3, studies by Smith and Micheli (1982), Dubravcic-Simunjak et al. (2003), and Fortin and Roberts (2003) all report that most figure-skating injuries (44.2–69.2%), grouping the disciplines together, are due to overuse. Singles skaters in the study by Dubravcic-Simunjak et al. (2003) experienced twice as many injuries as pairs and nine times as many injuries as dancers, and those injuries were overwhelmingly due to overuse. In Smith and Micheli's (1982) study, twice as many female singles and pairs skaters as male counterparts sustained overuse injuries. In their study involving pairs and ice dancers, Smith and Ludington (1989) reported that the 16 "less serious" injuries in their study were dominated by overuse pathology. Smith and Ludington (1989) also pointed out in their study that serious injuries to the foot and ankle tended to be due to overuse, but at all other anatomical sites they tended to be acute.

Pairs, dance, and synchronized skaters seem to incur mostly acute injuries (Smith & Ludington 1989; Dubravcic-Simunjak et al. 2003, 2006). Furthermore, Smith and Ludington (1989) found that out of 49 injuries incurred by pairs and dance skaters in their study, 63.6% of 33 serious injuries (defined as causing ⩾7 consecutive days of missed or markedly limited normal training) were acute. Furthermore, pairs skaters sustained over twice as many serious acute injuries as ice dancers. Dubravcic-Simunjak et al. (2003) concur, reporting four times as many acute injuries in pairs skaters as ice dancers. In addition, among 528 synchronized skaters, Dubravcic-Simunjak et al. (2006) found an overwhelming predominance of acute injuries.

Chronometry

Few figure skating studies assessed time into practice, time of day, or time of season. Brock and Striowski (1986) remarked that acute injuries were distributed equally among the first, second, and third thirds of the practice session. No pattern for overuse injuries seemed apparent.

In a small study of stress fractures in skaters, Pecina et al. (1990) reported almost as many injuries during preseason training (i.e., running, 44.4%) as during the regular season's on-ice practice (55.6%). Unfortunately, exposure data were not reported for on-ice practice, thus preventing a statistical comparison.

Fatigue was reported as occurring during the last minute of the skaters' long program based on highly elevated blood lactate concentration (Kjaer & Larsson 1992). Blood lactate concentration rose from a mean (±SD) of 2.2±0.8 and 1.5±0.5mM in male and female skaters, respectively, just before skating their long programs, to 9.0±1.3 and 7.4±0.6mM at the end of the skate. Elevated blood lactate concentrations in skaters could reduce their coordination during the last demanding minute of their program, thus perhaps putting them at risk of injury.

Table 27.2 Percent comparison of anatomical location of injuries in figure skating.

	Dubravcic-Simunjak et al. (2006)		Dubravcic-Simunjak et al. (2003)					
No. of participants:	528		469					
No. of injuries:	572		373					
Event(s):	Synchro		Singles		Pairs		Dance	
	M	F	M	F	M	F	M	F
	14	514	104	107	61	61	68	68
Head	*10.5*	*15.2*			*9.1*	*13.6*	*5.6*	
Head	10.5	14.3			9.1	13.6	5.6	
Face								
Skull								
Neck		0.9						
Spine/trunk		*4.2*	*14.0*	*12.5*	*12.7*	*8.5*		
Ribs								
Torso								
Back		0.4						
Low Back		3.6	14.0	12.5	12.7	8.5		
Abdomen		0.2						
Upper extremity	*21.1*	*23.7*	*3.3*	*1.8*	*16.4*	*10.1*	*11.1*	
Shoulder	5.3	3.4			5.5	3.4		
Arm		1.4	3.3	1.8	3.6	6.7		
Elbow		3.3						
Forearm		4.3						
Wrist	5.3	5.2			5.5		11.1	
Hand								
Finger	10.5	6.1			1.8			
Lower extremity	*68.4*	*53.9*	*82.6*	*85.7*	*61.8*	*67.8*	*83.3*	*100*
Hip/groin	5.3	7.2	8.3	7.1	5.5	3.4	22.2	12.5
Thigh/hamstring		3.6	2.5	4.5	3.6			
Knee	36.8	20.1	31.4	24.1	16.4	16.9	5.6	
Leg/shin	15.8	8.3	15.7	23.2	23.6	28.8	33.3	50.0
Ankle	10.5	7.8	14.0	14.3	12.7	15.3	11.1	25.0
Heel/Achilles		2.7	4.1	3.6				12.5
Foot		4.2	6.6	8.9		3.4	11.1	
Toes								
Other		*2.9*[a]						
Total injuries	19	553	121	112	55	59	18	8
Total %	100	99.9	99.9	100	100	100	100	100

[a] Sixteen stress fractures were reported, but their locations were not specified.

Fortin & Roberts (retrospective data) (2003)						Fortin & Roberts (prospective data) (2003)						Brown & McKeag (1987)			
208						208						14			
285						55						48			
Singles		Pairs		Dance		Singles		Pairs		Dance		Singles		Pairs	
M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
45	45	30	30	29	29	45	45	30	30	29	29	7	7	7	7
9.4	*5.4*	*15.3*	*13.8*	*11.5*	*20.0*			*12.5*	*9.1*			*10.7*		*100*	*14.3*
6.3	3.6	11.5	13.8	11.5	16.7							10.7		100	14.3
3.1	1.8	3.8			3.3			12.5	9.1						
18.8	*18.2*	*15.4*	*12.1*	*11.5*	*13.3*	*26.7*	*9.1*		*18.2*	*33.3*		*14.3*	*18.2*		*14.3*
															14.3
												14.3	18.2		
18.8	18.2	15.4	12.1	11.5	13.3	26.7	9.1		18.2	33.3					
3.1	*5.5*	*17.3*	*3.4*	*3.8*	*6.7*	*13.3*	*9.1*	*50.0*	*27.3*	*33.3*	*42.9*	*14.3*			*28.6*
3.1	5.5	17.3	3.4	3.8	6.7		9.1	37.5	9.1		28.6				14.3
												10.7			
									9.1		14.3	3.6			
						13.3				33.3					14.3
								12.5	9.1						
68.8	*70.9*	*52.0*	*70.7*	*73.1*	*60.1*	*59.9*	*81.9*	*37.5*	*45.5*	*33.3*	**57.2**	*60.7*	*81.8*		*42.9*
	7.3	7.7	8.6	15.4	6.7	20.0	18.2		18.2	33.3		3.6	54.5		28.6
25.0	10.9	9.6	20.7	23.1	26.7	13.3	18.2	37.5	9.1		28.6	39.3			
10.9	20.0	5.8	13.8	7.7	6.7	13.3	36.4		18.2		14.3		18.2		14.3
31.3	32.7	23.1	27.6	26.9	20.0		9.1								
												7.1	9.1		
1.6		5.8				13.3					14.3	10.7			
64	55	52	58	26	30	15	11	8	11	3	7	28	11	2	7
100.1	100	100	100	99.9	100.1	99.9	100.1	100	100.1	99.9	100.1	100	100	100	100.1

Table 27.3 Percent comparison of nature of onset in figure skating injuries.

Study	Design	No. of Injuries	No. of Subjects and Level	Injury Onset:		
				Overuse (gradual)	Acute (sudden)	Back Pain[a]
Sngles, Pairs, Dance:						
Dubravcic-Simunjak et al. (2003)	R	373 total:	469 junior level	55.5:	33.2:	11.3:
Singles:		*234*	*211*	*44.2*	*10.5*	*8.0*
Men		124	104	22.8	6.2	4.3
Women		110	107	21.4	4.3	3.8
Pairs:		*113*	*122*	*8.9*	*18.2*	*3.2*
Men		53	61	3.8	8.6	1.9
Women		60	61	5.1	9.7	1.3
Dance:		*26*	*136*	*2.4*	*4.6*	*0.0*
Men		17	68	1.9	2.7	0.0
Women		9	68	0.5	1.9	0.0
Fortin & Roberts (2003)	R	285	208 senior, junior, novice: 90 single 60 pair 58 dance	"Mostly overuse" (no data provided)		15.4
	P	55				
Brock & Striowski (1986)	R	28[b]	60 junior & senior	42.9	50.0	—
Singles:						
Kjaer & Larsson (1992)	P	18	8	44.4	55.6	—
Singles, Pairs:						
Smith & Micheli (1982)	R	52 total:	19 completed at least the 3rd figure or silver pairs test M = 4 F = 15	69.2:	30.8	
Men		19 Men		23.1 Men	13.5 Men	—
Women		33 Women		46.1 Women	17.3 Women	—
Pairs, Dance:						
Smith & Ludington (1989)	P	33 serious[c] 16 less serious[c]	48 senior, junior and novice levels	36.4 serious: 21.2 pairs 15.2 dance 62.5 less serious	63.6 serious: 45.5 pairs 18.2 dance 37.5 less serious	
Synchronized:						
Dubravcic-Simunjak et al. (2006)	R	572 total:	528 senior level	28.0	72.0:	
Men		19	14	0.9	2.4	
Women		553	514	27.1	69.6	

F = female; M = male; P = prospective; R = retrospective.

[a] Although back pain is not typically considered a type of injury onset, it is included here because the skaters in one study did not identify it as either overuse or acute on their questionnaire.

[b] Two injuries were unrelated to skating: one case of mononucleosis and one posttraumatic chondromalacia patellae arising from non-skating activity; nonetheless, the skaters were kept "off the ice or impaired," and therefore met the injury definition for this study.

[c] "Serious" injuries were defined as causing ⩾7 consecutive days of missed or markedly limited normal training. "Less serious" injuries were defined as either causing marked limited training for <7 days, or causing minor changes in training for ⩾4 weeks.

What Is the Outcome?

Injury Type

Table 27.4 shows the percent distribution of injury types reported in studies that stratified their data by sex and skating discipline. The percentages should be viewed with caution, given the varying definitions of injury types indicated in the table's footnotes.

Low back pain is unevenly represented in the table, although it receives respectable attention in the literature. Dubravcic-Simunjak et al. (2003) rank it second among injury types in their study, whereas Smith and Micheli (1982), not included in this table because their data are stratified incompatibly with the studies in Table 27.4, ranked low back pain first. All injuries incurred by young athletes going through their growth spurt are disturbing, but low back injuries are of particular concern. Kujala and associates (1996) reported that low back pain occurred only with intensive physical loading during the adolescent growth spurt. Their longitudinal prospective study with controls included 17 female figure skaters among the athlete cohort.

Stress fractures are not rare in figure skaters (Pecina et al. 1990), even though they seem relatively absent from the tables. Pecina et al. (1990), in their retrospective study of stress fractures over the careers of 42 world-class figure skaters, found 21.4% had experienced stress fractures in the take-off leg for jumps during their skating careers.

Table 27.4 does not include medical conditions; however, a condition that may cause injury to the airways has gained attention in the research literature in the past 10 years. Exercise-induced bronchospasm and exercise-induced asthma have been significantly related to winter sports in general and figure skating specifically (Mannix et al. 1996a; Weiler & Ryan 2000).

Time Loss

Injuries severe enough to keep skaters away from practice can and do occur. The few studies that have documented time away from practice have chosen different ways to present their data, as serious versus less serious injuries, or as specific number of days off, or as a percentage of the total training days missed. Brown and McKeag (1987) calculated that the 48 injuries in their study of pairs skaters caused the skaters to miss 493 days of training (singles, 408; pairs, 85), or 10.3 successive days per injury. It is important to note, however, that the data for singles injuries came from their pre-pairs careers as singles skaters, which lasted 2.8 years longer than their pairs careers. In their singles skating careers, muscle pull was the predominant injury type, but fractures (ranked second) accounted for the most lost training days (48%). In pairs, concussion accounted for 41% of lost training time. By anatomical location, axial injuries (44%) in pairs accounted for 66% of missed training days; in singles, the knee (28%) accounted for 44% of missed training days. Micheli and McCarthy (1996) reported that among the 175 skating injuries seen in their clinic, back injuries (8%) had a higher level of severity than the other skating injuries.

In their study of eight elite Danish singles skaters, Kjaer and Larsson (1992) reported that 18 injuries averaged a time loss of 4 days (range, 1–12 days) per injury. Nine stress fractures were described by Pecina et al. (1990), which took 3 to 7 months to rehabilitate. Brock and Striowski (1986) reported that skaters who sustained acute injuries tended to return to the ice sooner (12.2 days), as compared with overuse injuries (17.9 days). Stroking injuriescaused 9.7 days off and jumping 14.1 days. But acute injuries from stroking accounted for the longest time off (14.7 weeks). There were two meniscal knee injuries included in these, thus accounting for the long recovery time.

In singles, pairs, and ice dancers, Smith and Micheli (1982) found that most of the reported injuries (44 of 52) required $\leqslant 3$ days per injury, but 8 of 52 injuries were serious enough to require >3 days off per injury. Leaving out singles skaters and studying only pairs and ice dancers, Smith and Ludington (1989) reported that most of the injuries were more serious (33 of 49), requiring $\geqslant 7$ days off per injury as compared with 16 less serious injuries requiring <7 days off per injury. They also pointed out that serious injuries to the foot and ankle (8 of 33) tended to be due to overuse, and serious injuries to the knee (7 of 33) tended to be the result of acute trauma.

Table 27.4 Percent comparison of types of injuries in figure skating.

	Dubravcic-Simunjak et al. (2006)		Dubravcic-Simunjak et al. (2003)						Fortin & Roberts (2003)						Brown & McKeag (1987)			
No. of participants:	528		469						208						14 as singles/pairs			
No. of injuries:	572		373						55 (prospective)						48			
Event(s):	Synchro		Singles		Pairs		Dance		Singles		Pairs		Dance		Singles		Pairs	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
	14	514	104	107	61	61	68	68	45	45	30	30	29	29	7	7	7	7
Achilles tendinitis		2.7	4.1	3.6				12.5										
Ankle impingement		1.8	4.1	2.7														
Bursitis									6.7	9.1								
Concussion	5.3	3.6													11.1		100.0	14.3
Contusion, bruise	15.8	21.5								18.2	12.5	9.1		25.0				
Dislocation					5.3	3.4												14.3
Fracture	5.3	6.0	6.6	4.5	14.0	10.2	12.5		6.7			9.1			29.6			28.6
Groin pain		3.6	8.3	7.1	5.3	3.4	25.0	12.5										
Hamstring syndrome		1.8	2.5	4.5	3.5													
Head injury	—[a]	—[a]			8.8	13.6	6.3											
Hematoma		6.7													7.4	41.7		28.6
Joint pain, injury																		
Jumper's knee	10.5	5.4	14.0	13.4	3.5	6.8												
Knee pain, injury	—[b]	—[b]	2.5		1.8	3.4												
Laceration	26.3	15.6			8.8	13.6	25.0	50.0	13.3		12.5	18.2	50.0	12.5		16.7		14.3
Ligamentous	10.5	3.6							26.7	9.1	37.5	18.2	50.0					
Low back pain	—[c]	—[c]	13.2	12.5	12.3	8.5			—[d]	—[d]		—[d]	—[d]					
Meniscal														12.5				
Muscle spasm, strain									6.7	18.2				37.5	40.7	33.3		
Osgood–Schlatter	10.5	2.7	12.4	8.0	7.0	5.1												
Plantar fasciitis, pain		2.5	3.3	1.8														
Shin splints or pain	5.3	4.5	6.6	12.5	7.0	6.8	12.5											
Sprain			10.7	11.6	15.8	15.3	18.8	25.0							7.4	8.3		
Sprain/strain	10.5	11.6																
Stress fracture		2.9	11.6	17.9	7.0	10.2												
Tendinous[e]									40.0	45.5	37.5	36.4		12.5				
Other		3.4													3.7			
Injuries in column	19	553	121	112	57	59	16	8	15	11	8	11	2	8	27	12	2	7
Total %	100.0	99.9	99.9	100.1	100.1	100.3	100.1	100.0	100.1	100.1	100.0	100.1	100.0	100.0	99.9	100.0	100.0	100.1

F = female; M = male.
[a] Head injury was distributed among concussion, contusion and laceration in this study.
[b] Knee injuries can be found under ligamentous/meniscal, contusion, hematoma and laceration in this study.
[c] Low back and thoracic back injuries are distributed under contusion and "others" in this study.
[d] Low back injury is included under other types that were not all identified in this study.
[e] Includes tendinitis and tendinosis.

Clinical Outcome

There are only four reports in the literature that address clinical outcome. Kujala and colleagues (1996), in their longitudinal study with controls, briefly reported that 1 boy athlete and 6 girl athletes (which included both figure skaters and gymnasts) gave up competitive sports during the second and third follow-up years of the study, two because of low back pain and four for undisclosed reasons. A surprisingly high number of reinjuries (63.6%) were reported by Fortin and Roberts (2003) in the prospective portion of their study. Smith and Micheli (1982) reported that one boy had recurrent mild ankle sprains and another boy had recurrent groin muscle strains. In Smith and Ludington's (1989) prospective study of pairs and dancers, they described overuse injuries related to previous surgeries in one male and two female skaters, and one injury related to difficulty rehabilitating a strained and restrained muscle. No studies addressed catastrophic injury and residual effects.

Economic Cost

No studies were found that address costs of treating and rehabilitating figure-skating injuries.

What Are the Risk Factors?

Identifying injuries and their risk factors so that prevention strategies can be developed is a goal of epidemiologic research. In figure skating, limited attention has been given to analysis of risk factors for predictor variables. The difficulty with these studies is that the study populations were small, thus limiting precise analysis within subgroups. These studies are summarized in Table 27.5.

Intrinsic Factors

Physical and Physiologic Characteristics

Oleson and her associates (2002) designed a retrospective/cross-sectional study, with controls, on stress fractures in relation to bone mineral density (BMD), body mass index (BMI), calcium (Ca) intake, and hours of exercise. Skaters with no history of stress fracture had greater BMD in both heels than skaters with a history of stress fractures (right heel, $P = 0.001$; left heel, $P = 0.035$) as well as controls (right heel, $P<0.001$; left heel, $P = 0.001$). They also found an increased risk of stress injury associated with higher BMI ($P = 0.006$), higher Ca intake ($P = 0.002$), and lower amounts of weekly exercise ($P = 0.003$) when comparing skaters with no history of stress fracture with controls. The higher Ca intake in the skaters with a history of stress fracture was significant ($P = 0.003$) as compared with both controls and skaters with no history of stress fracture.

Sex as a predictor variable was analyzed in two studies (Brown & McKeag 1987; Smith et al. 1991), but the findings were not statistically significant.

Motor/Functional Characteristics

In their prospective study with pretests and posttests, Smith et al. (1991) measured skaters for muscle tightness in the quadriceps, hamstrings, and iliotibial band in relation to anterior knee pain. In addition to the significant findings shown in Table 27.5, the authors found quadriceps tightness to be the most prevalent flexibility problem in skaters with anterior knee pain.

Growth Spurt

Kujala et al. (1996) reported that severe low back pain and lesions occurred only during the adolescent growth spurt ($P <0.05$) and pointed out that no episodes existed prior to the study.

Extrinsic Factors

Environment

Although studies exist that have tested the cold-air environment of winter sports as a predictor of exercise-induced asthma or exercise-induced bronchospasm (Mannix et al. 1996a; Provost-Craig et al. 1996; Wilber et al. 2000) and linked it to performance results (Weiler & Ryan 2000), they did not relate this condition to musculoskeletal injury.

What Are the Inciting Events?

Some of the studies reviewed thus far have attempted to identify inciting events that have led

Table 27.5 Risk factors in epidemiologic studies of figure skating injuries.

Sudy	Subjects	Statistical analysis	Variables studied	Results
Oleson et al. (2002)	26 skaters w/o stress fracture; 10 skaters with stress fracture; 22 age-matched controls	Scheffé's multiple comparison tests; Independent samples *t* tests; Pearson's product moment correlation coefficient; Significance defined as $P \leq 0.05$.	a. *BMI*	a. BMI was significantly lower in skaters w/o stress fractures than controls ($P = 0.006$).
			b. *Training load*	b. Skaters w/o fractures exercised more hr/wk for greater number of yr than controls ($P = 0.003$). Skaters w/ fractures exercised more hr/wk than controls; only marginally significant at $P = 0.057$
			c. *Diet*	c. Calcium intake was higher in skaters w/fracture history ($P = 0.002$), as compared with skaters w/o fracture history and controls.
			d. *Age*	d. Skaters who were <10 yr old when they mastered their first double jump had fewer stress fractures than skaters who were >10 yr old before achieving double jumps, nonsignificant at $P = 0.06$.
			e. *BMD*	e. Skaters w/o a stress fracture history had greater BMD in the right heel than skaters w/stress fractures ($p = .001$) controls ($P < 0.001$). For the left heel, the differences were significant at $P = 0.035$ and $P = 0.001$, respectively.
Kujala et al. (1996)	98 (elementary-school age): 33 controls; 65 athletes, including 17 female figure skaters	Chi-square test, Fisher's exact test (two-tailed), and ANOVA and CI	a. *Growth spurt*	a. Severe low back pain and lesions occurred only during the growth spurt of adolescence ($P < 0.05$); none had occurred before the study began.
Smith et al. (1991)	46 elite juniors	Fisher's exact test	a. *Flexibility: quadriceps*	a. Rectus femoris muscle tightness was greater in female skaters w/anterior knee pain than in skaters with no knee pain ($P < 0.05$); the same seemed to be true for male skaters but it was not significant statistically.

				17 of 19 lower extremities with knee pain had tight quadriceps as compared with only 39 of 73 lower extremities w/o knee pain ($P < 0.01$).
			b. *Flexibility: QFA*	b. QFA was greater in male skaters with jumper's knee than in male skaters w/no knee pain ($P < 0.0005$). QFA was greater in female skaters with jumper's knee ($P<0.05$), Osgood–Schlatter disease ($P < 0.01$), or isolated patellofemoral pain ($P < 0.05$) as compared with female skaters with no knee pain.
			c. *Flexibility: hamstrings*	c. Hamstring tightness was present in female skaters with isolated patellofemoral pain ($P<0.005$), and in all cases of patellofemoral pain secondary to either jumper's knee or Osgood–Schlatter disease ($P<0.05$). For male skaters, there was no significant relation-ship.
Brown & McKeag (1987)	14 pair skaters: M = 7 F = 7	Chi-square test	*Sex:* Difference in the no. of injuries between M and F, after adjusting for M–F differences in length of participation as a singles or pairs skater.	a. In their singles skating history, males sustained most of the injuries (72%), nonsignificant at $P = 0.11$. b. In their pairs skating history, female skater s sustained most of the injuries (78%), but not significantly so.

ANOVA = analysis of variance; BMD = bone mineral density; BMI = body-mass index; CI = confidence interval; F = female; M = male; QFA = quadriceps flexion angle; w/ = with; w/o = without.

to injuries in skaters, some more casually than others. The common events that were repeatedly identified are jumping/landing, falling, colliding, and lifting.

Jumping/Landing

Jumps are implicated in most of the injuries incurred in figure skaters and in every anatomical location, and there is concern among the researchers about these injuries occurring during preadolescence and the growth spurts. Brock and Striowski (1986) found that 57.1% of the acute injuries, or 28.6% of all injuries reported in their retrospective study, occurred during jumping. Almost all of the overuse injuries in the lower extremities of singles skaters have been attributed in some way to the landing forces (Podolsky et al. 1990; Lockwood & Gervais 1997) in general, and specifically to the forces generated by pushing off from and/or landing onto an excessively pronated foot during intensive jumping exercises (Smith & Micheli 1982; Brown & McKeag 1987; Pecina et al. 1990; Dubravcic-Simunjak et al. 2003; Fortin & Roberts 2003). Most studies, excepting Pecina et al. (1990), attribute jump-related injury to the landing foot. That seems to have been confirmed by Oleson and associates (2002) in their study of bone density, finding that the landing leg indeed has greater estimated BMD than the take-off leg. Jumping has also been associated with low back injuries (Smith & Micheli 1982; Fortin & Roberts 2003), some acute and some overuse, especially during periods of rapid growth (Kujala et al. 1996).

Falling

Falls sometimes occur because a jumping or landing action went wrong. In those cases, concussions, contusions, upper extremity fractures, and lumbar spine injuries have been reported (Kujala et al. 1996; Oleson et al. 2002; Dubravcic-Simunjak et al. 2003, 2006; Fortin & Roberts 2003), quite often in skaters attempting double and triple jumps. Falling was cited as a key inciting event in pairs skating because of daring lifts and tosses (Brock & Striowski 1986; Dubravcic-Simunjak et al. 2003), in ice dancing because of some lifting but also because of the proximity of the partners throughout the program (Dubravcic-Simunjak et al. 2003) and in synchronized skating likewise because of lifts and proximity (Dubravcic-Simunjak et al. 2006). Finally, four senior female dancers in Smith and Ludington's (1989) study suffered five serious injuries, four of them from falls.

Colliding

Most collision injuries have been reported in synchronized skating. Dubravcic-Simunjak et al. (2006) found that team elements, such as intersecting maneuvers (28.7%) and moving as a block down the ice (21.0%), accounted for 73.1% of 247 acute injuries during on-ice practice. Collision-type injuries also occur in singles, pairs, and dance. Smith and Ludington (1989) and Smith and Micheli (1982) described injuries that included an elbow to the face in pairs and two singles skaters who collided, respectively.

Lifting

Smith and Ludington (1989) reported that 11 (33.3%) of the 33 serious injuries in their study were caused by lifts in pairs skaters. In synchronized skating 18.2% of 247 acute on-ice injuries during team practice were due to lifts, and almost half of those (46.7%) were head injuries (Dubravcic-Simunjak et al. 2006).

Injury Prevention

As robust as the figure skating research literature is, it is frustrating to admit that no intervention studies were found that measured the effectiveness of an injury prevention or reduction strategy.

Further Research

More epidemiologic studies, both descriptive and analytical, need to be conducted in order to bring us closer to a congruent picture of figure skating injuries. Those studies should account for the multivariate nature of figure skating injuries by including sufficient sample sizes and as many relevant risk factors as possible (Bahr & Holme 2003).

Descriptive Epidemiology

Because of variations in definitions and methods of data collection and reporting in injury surveillance, risk factor, and intervention studies, interstudy comparisons of figure skating injuries are difficult, if not impossible. It seems reasonable for a consensus statement to be published that would assist researchers in the details of designing and carrying out their studies, similar to the statement developed by an Injury Consensus Group of the Fédération Internationale de Football Association Medical Assessment and Research Center in 2005 (Fuller et al. 2005). Their statement provides definitions for injury, recurrent injury, injury severity, and training exposure, and then it provides guidelines on designing the study, data-collection forms, and specific guidelines on reporting the data.

Analytical Epidemiology

Studies that address risk factors for their predictive value are virtually nonexistent in the figure skating literature. Although there is evidence in the literature that the factors listed below can predispose the skater to injury or perhaps be associated with a protective effect against injury, future study designs need to include plans for analysis of all of the possible variables that may or may not prompt injury.

- The unyielding structure of skating boots (Davis & Litman 1979; Smith & Micheli 1982; Brock & Striowski 1986; Smith & Ludington 1989; Bloch 1999; Brown et al. 2000, Varney & Micheli 2000; Dubravcic-Simunjak et al. 2003; Anderson et al. 2004; Bruening & Richards 2006)
- The quality of air in skating rinks (Brauer & Spengler 1994; Bloch 1999)
- The condition of the ice (Bloch 1999; Brock & Striowski 1986)
- Nutritional disorders (Jonnalagadda et al. 2004; Rucinski 1989)
- Menstrual dysfunction (Slemenda & Johnston 1993)
- Fitness level of skaters (McMaster et al. 1979; Kjaer & Larsson 1992; Mannix et al. 1996b)
- Bone mineral density (Pecina et al. 1990; Slemenda & Johnston 1993; Oleson et al. 2002)
- Increased risk of injury during growth spurt (Smith & Micheli 1982; Smith et al. 1991; Kujala et al. 1996; Dubravcic-Simunjak et al. 2003; Smith 2003)
- Impact forces during take-off and landing of jumps (Pecina et al. 1990; Lockwood & Gervais 1997)
- Flexibility (Smith et al. 1991; Micheli et al. 1999)

With regard to injury prevention, no intervention studies in figure skating surfaced during the literature search. Future intervention studies need to be randomized controlled trials, if possible, to reduce problems of bias and confounding variables that affect the power of nonrandomized designs (Walter & Hart 1990). To this end, I have attempted to identify methodologic weaknesses in the literature, to underscore the need for well-designed studies that can lead to informed decisions about injury prevention programs, and to suggest specific areas of further research that would test the possible interventions that were addressed in the literature.

References

Anderson, S.E., Weber, M., Steinbach, L.S. & Ballmer, F.T. (2004) Shoe rim and shoe buckle pseudotumor of the ankle in elite and professional figure skaters and snowboarders: MR imaging findings. *Skeletal Radiology* **33,** 325–329.

Bahr, R. & Holme, I. (2003) Risk factors for sports injuries—a methodological approach. *British Journal of Sports Medicine* **37,** 384–392.

Bloch, R.M. (1999) Figure skating injuries. *Physical Medicine and Rehabilitation Clinics of North America* **10,** 177–188, vii.

Brauer, M. & Spengler, J.D. (1994) Nitrogen dioxide exposures inside ice skating rinks. *American Journal of Public Health* **84,** 429–433.

Brock, R.M. & Striowski, C.C. (1986) Injuries in elite figure skaters. *Physician and Sportsmedicine* **14,** 111–115.

Brown, E.W. & McKeag, D.B. (1987) Training, experience, and medical history of pairs skaters. *Physician and Sportsmedicine* **15,** 101–114.

Brown, T.D., Varney, T.E. & Micheli, L.J. (2000) Malleolar bursitis in figure skaters: indications for operative and nonoperative treatment. *American Journal of Sports Medicine* **28,** 109–111.

Bruening, D.A. & Richards, J.G. (2006) The effects of articulated figure skates on jump landing forces. *Journal of Applied Biomechanics* **22,** 285–295.

Caine, D. & Nassar, L. (2005) Gymnastics injuries. In: *Epidemiology of Pediatric Sports Injuries: Individual Sports* (Caine, D.J. & Maffulli, N., eds.), Karger, Basel, Switzerland, pp. 18–58.

Davis, M.W. & Litman, T. (1979) Figure skater's foot. *Minnesota Medicine* **62,** 647–648.

Dubravcic-Simunjak, S., Kuipers, H., Moran, J., Simunjak, B., & Pecina, M. (2006) Injuries in synchronized skating. *International Journal of Sports Medicine* **27,** 493–499.

Dubravcic-Simunjak, S., Pecina, M., Kuipers, H., Moran, J. & Haspl, M. (2003) The incidence of injuries in elite junior figure skaters. *American Journal of Sports Medicine* **31,** 511–517.

Fortin, J.D. & Roberts, D. (2003) Competitive figure skating injuries. *Pain Physician* **6,** 313–318.

Fuller, C.W., Ekstrand, J., Junge, A., Andersen, T.E., Bahr, R., Dvorak, J., Hägglund, M., McCrory, P. & Meeuwisse, W.H. (2005) Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *British Journal of Sports Medicine* **40,** 193–201.

International Olympic Committee website. (2008) URL http://www.olympic.org [accessed March 24, 2008].

Jonnalagadda, S.S., Ziegler, P.J. & Nelson, J.A. |(2004) Food preferences, dieting behaviors, and body image perceptions of elite figure skaters. *International Journal of Sport Nutrition and Exercise Metabolism* **14,** 594–606.

Kjaer, M. & Larsson, B. (1992) Physiological profile and incidence of injuries among elite figure skaters. *Journal of Sports Sciences* **10,** 29–36.

Kujala, U.M., Taimela, S., Erkintalo, M., Salminen, J.J. & Kaprio, J. (1996) Low-back pain in adolescent athletes. *Medicine and Science in Sports and Exercise* **28,** 165–170.

Lockwood, K.L. & Gervais, P.L. (1997) Impact forces upon landing single, double, and triple revolution jumps in figure skaters. *Clinical Biomechanics* **12,** S11.

Mannix, E.T., Farber, M.O., Palange, P., Galassetti, P. & Manfredi, F. (1996a) Exercise-induced asthma in figure skaters. *Chest* **109,** 312–315.

Mannix, E.T., Healy, A. & Farber, M.O. (1996b) Aerobic power and supramaximal endurance of competitive figure skaters. *Journal of Sports Medicine and Physical Fitness* **36,** 161–168.

Mannix, E.T., Manfredi, F. & Farber, M.O. (1999) A comparison of two challenge tests for identifying exercise-induced bronchospasm in figure skaters. *Chest* **115,** 649–653.

McMaster, W.C., Liddle, S. & Walsh, J. (1979) Conditioning program for competitive figure skating. *American Journal of Sports Medicine* **7,** 43–47.

Micheli, L.J., Glassman, R. & Klein, M. (2000) The prevention of sports injuries in children. *Clinics in Sports Medicine* **19,** 821–834.

Micheli, L.J., Greene, H.S., Cassella, M., Gruber, J. & Zurakowski, D. (1999) Assessment of flexibility in young female skaters with the modified Marshall Test. *Journal of Pediatric Orthopaedics* **19,** 665–668.

Micheli, L.J. & McCarthy, C.F. (1996) Figure skating. In: *The Spine in Sports* (Watkins, R.G., ed.), Mosby-Yearbook, St. Louis, pp. 557–563.

Oleson, C.V., Busconi, B.D. & Baran, D.T. (2002) Bone density in competitive figure skaters. *Archives in Physical Medicine and Rehabilitation* **83,** 122–128.

Pecina, M., Bojanic, I. & Dubravcic, S. (1990) Stress fractures in figure skaters. *American Journal of Sports Medicine* **18,** 277–279.

Podolsky, A., Kaufman, K.R., Cahalan, T.D. Aleshinsky, S.Y. & Chao, E.Y.S. (1990) The relationship of strength and jump height in figure skaters. *American Journal of Sports Medicine* **18,** 400–405.

Provost-Craig, M.A., Arbour, K.S., Sestili, D.C., Chabalko, J.J. & Ekinci, E. (1996) The incidence of exercise-induced bronchospasm in competitive figure skaters. *Journal of Asthma* **33,** 67–71.

Rucinski, A. (1989) Relationship of body image and dietary intake of competitive ice skaters. *Journal of the American Dietetic Association* **89,** 98–100.

Slemenda, C.W. & Johnston, C.C. (1993) High intensity activities in young women: site specific bone mass effects among female figure skaters. *Bone and Mineral* **20,** 125–132.

Smith, A.D. (2000) The young skater. *Clinics in Sports Medicine* **19,** 741–755.

Smith, A.D. (2003) The skeletally immature knee: what's new in overuse injuries. *Ann Arbor Orthopaedic Surgery (AAOS) Instructional Course Lectures* **52,** 691–697.

Smith, A.D. & Ludington, R. (1989) Injuries in elite pairs skaters and ice dancers. *American Journal of Sports Medicine* **17,** 482–488.

Smith, A.D. & Micheli, L.J. (1982) Injuries in competitive figure skaters. *Physician and Sportsmedicine* **10,** 36–47.

Smith, A.D., Stroud, L. & McQueen, C. (1991) Flexibility and anterior knee pain in adolescent elite figure skaters. *Journal of Pediatric Orthopaedics* **11,** 77–82.

U.S. Figure Skating Association website. (2008) URL http://www.usfsa.org [accessed August 9, 2008]

Walter, S.D. & Hart, L.E. (1990) Application of epidemiological methodology in sports and exercise science research. In: *Exercise and Sport Science Reviews,* no. 18. (Pandolf, K.B. & Holloszy, J.E., eds.), Williams & Wilkins, Baltimore, pp. 417–488.

Weiler, J.M. & Ryan, E.J. 3rd. (2000) Asthma in United States Olympic athletes who participated in the 1998 Olympic Winter Games. *Journal of Allergy and Clinical Immunology* **106,** 267–271.

Wilber, R.L., Rundell, K.W., Szmedra, L., Jenkinson, D.M., Im, J. & Drake, S.D. (2000) Incidence of exercise-induced bronchospasm in Olympic winter sport athletes. *Medicine and Science in Sports and Exercise* **32,** 732–737.

Ziegler, P.J., Jonnalagadda, S.S. & Lawrence, C. (2001) Dietary intake of elite figure skating dancers. *Nutrition Research* **21,** 983–992.

Ziegler, P.J., Kannan, S., Jonnalagadda, S.S., Krishnakumar, A., Taksali, S.E. & Nelson, J.A. (2005) Dietary intake, body image perceptions, and weight concerns of female U.S. international synchronized figure skating teams. *International Journal of Sport Nutrition and Exercise Metabolism* **15,** 550–566.

Ziegler, P.J., Khoo, C.S., Kris–Etherton, P.M., Jonnalagadda, S.S., Sherr, B. & Nelson J.A. (1998a) Nutritional status of nationally ranked junior U.S. figure skaters. *Journal of the American Dietetic Association* **98,** 809–811.

Ziegler, P.J., Khoo, C.S., Sherr, B., Nelson, J.A., Larson, W.M. & Drewnowski, A. (1998b) Body image and dieting behaviors among elite figure skaters. *International Journal of Eating Disorders* **24,** 421–427.

Chapter 28

Ice Hockey

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Introduction

The Society for International Hockey Research defines ice hockey as "a game played on an ice rink in which two opposing teams of skaters, using curved sticks, try to drive a small disc, ball or block into or through the opposite goals" (Society for International Hockey Research, 2001) (Figure 28.1). Over the years, ice hockey has become one of the most popular sports for both sexes throughout North America and Europe, with participation rates continuing to grow at all levels of involvement (Sane et al. 1988).

Since the early 1980s, Sweden has recorded over 50,000 players registered in organized leagues (Molsa et al. 1999). Finland has more than 60,000 licensed players in the Finnish Ice Hockey Association, playing more than 34,000 games a year (Molsa et al. 2003). Between 1965 and 1985, the United States experienced a fourfold increase in amateur team registrations (Finke et al. 1988). Today, the United States has over 18,000 registered teams with USA Hockey, more than 370,000 registered youths, and has seen an increase in high-school participation by 87% (Stuart & Smith

Figure 28.1 Direct and indirect games injuries can result from contact with the boards. Salt Lake City 2002—Preliminary round match, Kazakhstan versus Russia. © IOC/Yo NAGAYA.

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1995; Yard & Comstock 2006). In Canada, where ice hockey is considered a national pastime, there are more than 464,000 registered participants each season (Yard & Comstock 2006), with over 43,000 female registrants (Schick & Meeuwisse 2003).

Ice hockey has been linked to personal and physical well-being; however, increased participation has also led to a widespread incidence of injury. The potential for injury is derived from high puck and skating speeds, a propensity for aggressive behavior, and frequent collisions with boards, glass, ice, goal posts, skate blades, sticks, and other players (Goodman et al. 2001, Gaetz & Meichenbaum 2001). This combination makes ice hockey one of the fastest (Hawn et al. 2002, Visser & Sexton 2002; Miller et al. 2006) and most violent team sports in the world (Hawn et al. 2002; Willer et al. 2005). Other factors that can influence injury rates are age, gender, level of competition, type of competition (e.g., practice, exhibition game, league game, tournament game), amount of athlete-exposure, use of protective equipment, fatigue, rules and regulations, and style of play (Stuart et al. 2002). Unfortunately, injuries can result in physiological, emotional, psychological, and economical consequences.

A review of pediatric ice hockey literature explored injury trends, incidence rates, and inherent risks found at the adolescent and youth levels of competition (Benson & Meeuwisse 2005). This chapter will review the distribution and determinants of injuries reported in junior, college, and professional levels of ice hockey competition. Analysis of the data will be helpful to identify potential prevention strategies for ice hockey injuries.

Who Is Affected by Injury?

Incidence of Injury

Injury incidence in ice hockey is dependent on analyzing the number of new injuries presented within a fixed period with respect to the number of people at risk (Greenberg et al. 2005). A comparison of player injury rates across 18 studies is provided in Table 28.1. Two studies (Watson et al. 1997; Wennberg, 2005) reported only injury rates specific to games. Across the studies, injury rates were reported as per player-years, games, players, player-hours, and athlete-exposures (AEs). Studies also differed with respect to design, age groups, player position, rules and regulations, equipment worn, ice surface size, associations, leagues, and sources of data collection (e.g., athletic therapist, athletic trainer, physicians, emergency department visits, injury registry databases). Thus, a single, meaningful comparison across studies, level of competition, sex, and age was difficult to make.

Player Position

Table 28.2 highlights 19 studies that reported incidence of injury according to player position. Again, it is difficult to make a single comparison or meaningful range across studies because of the diversity in patterns and methods of reporting. Across all levels of competition, 15 (Jorgensen & Schmidt-Olsen 1986; McKnight et al. 1992, Ferrara & Czerwinska 1992; Pelletier et al. 1993; Stuart & Smith 1995; Molsa et al. 1997; Emery et al. 1999, Meeuwisse & Powell 1999; Ferrara & Schurr 1999; Pinto et al. 1999; Goodman et al. 2001; Groger 2001; Yohann 2001; Benson et al. 2002; Agel et al. 2007a, 2007b; Flik et al. 2005, Lyman & Marx 2005) of 16 studies reporting injury rates as a percent comparison observed higher proportions in forwards (45–66%) versus defensemen (25–57%), and goalkeepers (4–14%). Such percentages are intuitive and logical because there are three forwards, two defensemen, and one goalie playing at regular strength at any given time, and thus the exposure time at risk of injury is greater for forwards, followed by defenseman and goalies. The study by Pettersson and Lorentzon (1993) was the only one that reported a higher percentage of injuries suffered by defensemen (57%) versus forwards (36%) and goalkeepers (7%).

Seven studies reported injuries per 1,000 player-hours. Game injury rates in forwards (30–125 injuries/1,000 player-hours) were highest in four (Lorentzon et al. 1988b; Biasca et al. 1995; Yohann 2001; Groger 2001), whereas the rates in defensive players (50–151 injuries/1,000 player-hours) were highest in the others (Lorentzon et al. 1988a; Stuart & Smith 1995; Pinto et al. 1999). Consistently, goaltenders revealed lower game injury rates—4% to 14% and 0 to 39 injuries per 1,000 player-hours. This difference may be attributed to goalies wearing a greater amount of protective equipment, being confined to a smaller playing area with respect to total ice surface, and having a limited amount of direct body contact with respect to the other players, the boards, and plexiglas (McKnight et al. 1992).

Where Does Injury Occur?

Anatomical Location

Only 18 studies reported hockey injuries by anatomical location. Table 28.3 provides a percent comparison of these injuries.

Junior

Three of five studies reported injury location at the junior level (Table 28.3). The highest percentage of injuries were to the face (23–58%), since the majority of players at this level of competition do not wear full facial protection. The shoulder was another common injury location for junior ice hockey players (13–20%). Stuart and Smith (1995) revealed the pelvis and hip to be the most commonly injured body region of the lower extremity (14%), whereas Pinto et al. (1999) found a high percentage of thigh and groin injuries (13% in both forwards and defensemen).

College

Six of 12 studies reported injury location at the college level (Table 28.3). A high percentage of lower-extremity injuries was a common factor in all of them. Agel et al. presented practice and game injury percentages at 36% and 34% for men (Agel et al. 2007b), and 31% and 32% for women (Agel et al. 2007a), respectively. Flik et al. (2005) and Pelletier et al. 1993, Montelpare & Stark (1993) listed knees as having the highest percentage of injury (22% and 19%, respectively), while McKnight et al. (1992) and Yohann (2001) reported a high percentage of thigh and groin injuries (15% and 20%, respectively). Three studies listed the shoulder as the second highest injured location, at 12% (Yohann 2001), 15% (Pelletier et al. 1993), and 18% (McKnight et al. 1992). Both male and female college players experienced a greater percentage of injury to the spine and trunk in practice (26% in both), and a high percentage of injury to the upper (34% and 30%, respectively) and lower (34% and 32%) extremities during games.

Professional

Nine of 16 studies at the professional level reported injury location (Table 28.3). The percentage of injuries at this level of competition ranged from 32% to 54% in the lower extremity, 24% to 33% in the upper extremity, and 5% to 31% to the head and neck. The most commonly injured location in the lower extremity was the knee (13–24%). There was variable reporting in the upper extremity, the spine and trunk, and the head and neck.

Environmental Location

Games versus Practices

Table 28.4 summarizes injury rates according to practices and games. Twenty-four studies compared injury rates between games and practices, with all of them reporting a much higher rate of injury during games. Overall practice injury rates ranged from 11% to 37%, 0 to 5 injuries per 1,000 player-hours, and 1 to 5 injuries per 1,000 AEs. Lorentzon et al. 1998a, Wedren & Pietila (1988a) reported low injury rates in practice sessions and revealed that most injuries were of minor severity (i.e., absence from practice for ≤7 days). Overall game injury rates ranged from 3% to 100%, 5 to 480 injuries per 1,000 player-hours, and 4 to 22 injuries per 1,000 AEs. Benson et al. (2002) and Goodman et al. (2001) investigated concussion injury rates and found a higher incidence of concussions sustained during games versus practices. Four studies (Lorentzon et al. 1988a, 1988b; Tegner & Lorentzon 1996; Stuart et al. 2002) reported game injury rates only.

Three studies (Agel et al. 2007b; Agel et al. 2007a; Schick & Meeuwisse, 2003) reported the incidence of ice hockey injury in both male and female hockey players. All studies reported higher game injury rates for male and female players. Injury rates for college men ranged from 11 to 22 injuries per 1,000 AEs during games as compared with 1 to 5 injuries per 1,000 AEs during practices (Agel et al.

Table 28.1 Comparison of injury rates among junior, college, and professional ice-hockey players.

Study	Study Design	Data Collection (Source)	Age, yr	Duration of Study, No. of Seasons, yr	Sample, No. of Subjects (No. of Teams)
Junior					
Stuart et al. (1995)	P	Trainer, MD	17–20	3 (1990–1993)	25 (1)
Watson et al. (1997)	R	Athletic Therapist, Trainer	16–20	1 (1993–1994)	? (16)
College					
Schick & Meeuwisse (2003)	P/R	Team Therapist, Injury Registry (CISIR)	Mean: W: 20.9 M: 23.5	1 (1998–1999)	Overall: 261 (12) W: 114(6) M: 147 (6)
Benson et al. (1999)	P	Athletic Therapist	HFS: 18–29 FFS: 17–29	1 (1997–1998)	642 (22)
Benson et al. (2002)	P	Athletic Therapist	Median: 22	1 (1997–1998)	642 (22)
Ferrara & Schurr (1999); McKnight et al. (1992)	P	Trainer	?	3 (1987–1990)	? (7)
Flik et al. (2005)	P	Trainer	?	1 (2001–2002)	? (8)
Pelletier et al. (1993)	P	Injury Registry (CAIRS)	19–25	6 (1979–2985)	Mean: 19 players/game (?)
Watson et al. (1996)	P/R	Athletic Therapist, Trainer	?	6 (1986–1992)	? (3)
Professional					
Molsa et al. (1999)	R	MD, Telephone Interview	14–33	? (1980–1996)	?(?)

No. of Injuries	Injury Rate					
	Injuries/ 1,000 Player-yr	Injuries/ Game	Injuries/1,000 Player-Games	Injuries/100 Players	Injuries/1,000 Player-hr	Injuries/1,000 AEs
142					9.4	
LTS: 22 S: 134 STS: 172		O/Ne: LTS: 0.33/0 S: 0.58/0.02 STS: 0.76/0.03				
W: 66 M: 161						W: 7.77 M: 9.19
HFS: 204 FFS: 195						HFS: H/F: 3.54 CO: 1.53 N: 0.34 Other: 7.53 FFS: H/F: 1.41 CO: 1.57 N: 0.29 Other: 6.21
HFS: 41 FFS: 38						CO: 1.55
280						10.22
113						4.9
188			19.95			
H/N: <1989 – 26 >1989 – 16 Back: <1989 – 21 >1989 – 16 Shoulder: <1989 –68 >1989 – 69			H/N: <1989 – 6.16 >1989 – 4.49 Back: <1989 – 4.98 >1989 – 4.49 Shoulder: <1989 –16.11 >1989 – 19.38			
Spinal Cord Only: 16				0.011/1000 players		

(*continued*)

Table 28.1 (*continued*)

Study	Study Design	Data Collection (Source)	Age, yr	Duration of Study, No. of Seasons, yr	Sample, No. of Subjects (No. of Teams)
Emery et al. (199)	R	Team Therapist, Injury Registry (NHLISS)	?	6 (1991–191997)	7050 (?)
Emery & Meeuwisse (2001)	P	Team Therapist, Injury Registry (NHLISS)	?	1 (1998–1999)	1292 (23)
Jorgenson & Schmidt-Olsen (1986)	P	Quest.	16–34	2 (?)	266 (14)
Molsa et al. (1997)	P	MD	18–37	1 (1988–1989)	? (7)
Pettersson & Lorentzon (1993)	P	MD	Mean: 25	4 (1986–1990)	Mean: 22–25 players/ season (1)
Tyler et al. (2001)	P	MD	?	2 (1997–1999)	47 (1)
Wennberg & Tator, 2003	R	Trainer, MD	?	16 (1986–2002)	? (?)

AE = athlete-exposure; CAIRS = Canadian Athletic Injuries/Illness Reporting System (modification of the National Athletic Injuries/ League (second highest playing league in Finland); F = face; FFS = full face shield; FNL = Finish National League; H = head; HA = hip NHLISS = National Hockey League Injury Surveillance System; O = overall; P = prospective; R = retrospective; S = standard ice surface

2007b). College women also had reportedly higher game injury rates, ranging from 9 to 13 injuries per 1,000 AEs during games and 1 to 4 injuries per 1,000 AEs during practices (Agel et al. 2007a). Agel et al. (2007a) also reported a lower incidence of injury in women as compared with men, although Schick and Meeuwisse (2003) found that injury rates did not differ significantly; an interesting finding, since female ice hockey prohibits intentional body checking.

When Does Injury Occur?

Injury Onset

High acceleration and deceleration speeds, high puck velocities, shifts in momentum, unstable surfaces, and impacts during high-speed motion with players, boards, ice, equipment, and the environment (Sim & Chao 1978) combine to produce a higher frequency of acute traumatic injury as compared with injuries

No. of Injuries	Injury Rate					
	Injuries/ 1,000 Player-yr	Injuries/ Game	Injuries/1,000 Player-Games	Injuries/100 Players	Injuries/1,000 Player-hr	Injuries/1,000 AEs
Groin & Abdominal Only: Overall: 617 1995–97: 272				1991–92: 12.99 1996–97: 19.87		1995–97: 0.96
Groin & Abdominal Strain Only Camp: 52 1998–99: 152				Camp: 3.83 1998–99: 23.49		Camp: 2.87 1998–99: 1.33
189					4.7	
Overall: 189 FNL: 134 DIV: 55					Overall: 5.6 FNL: 5.8 DIV: 5.1	
376		1.2				
Overall: 141 HA Only: 15			3.2			17
CO: 451			CO: 209			

Illness Reporting System); CISIR = Canadian Intercollegiate Sport Injury Registry; CO = concussion only; DIV = Finnish Division I Men's adductor; HFS = half face shield; LTS = larger than standard ice surface (>17,000 ft^2); M = men; N = neck; Ne = neurotraumas only; (200 × 85 ft – 17,000 ft^2); STS = <standard ice surface (<17,000 ft^2); W = women.

resulting from overuse. This is reflected in Table 28.5, where all 7 of the 50 studies that accounted for injury onset reported a higher percentage of acute traumatic injuries, ranging from 80% to 100%.

Chronometry

Period of Game

Table 28.6 shows a percent comparison of injury rates across three periods of game play. At all levels of competition, the highest rates of injury were reported either in the second or third period. Eight studies (Lorentzon et al. 1988b; Tegner & Lorentzon 1991, 1996; Pelletier et al. 1993; Pettersson & Lorentzon 1993; Yohann, 2001; Schick & Meeuwisse 2003; Flik et al. 2005) reported a higher percentage of injuries in the second period, ranging from 32% to 65%. Three studies (Lorentzon et al. 1988a; Pinto et al. 1999; Molsa et al. 2000) reported higher rates in the third period, with percentages ranging from 36% to

Table 28.2 Comparison of injury rates among junior, collegiate, and professional ice hockey players by position.

Study	Age, yr	Sample, No. of Subjects (No. of teams)	No. of of Injuries	Injuries in Forwards			
				Total No. of Injuries (%)	Per 1,000 Player-Games	Per 1,000 Player-hr	Per 1,000 AEs
Junior							
Stuart & Smith (1995)	17–20	25 (1)	142			87	
Goodman et al. (2001)	15–20	Year 1: 272 (14) Year 2: 283 (14)	CO: 1: 29 2: 21	1: 58.1 2: 56.1			
Pinto et al. (1999)	16–20	22 (1)	74	63		138	
College							
Yohann (2001)	18–25	468 (1 team/ 15 seasons)	1251	59.6		122.4	
Benson et al. (2002)	Median: 22	642 (22)	HFS: 41 FFS: 38	HFS: 56.1 FFS: 63.2			
Ferrara & Schurr (1999); McKnight et al. (1992)	?	? (7)	280	58.2			11.4
Flik et al. (2005)	?	? (8)	113	61.1			5.1
Pelletier et al. (1993)	19–25	Mean: 19 players/ game (?)	188	66.0	20.83		
Agel et al. (2007a)	?	? (43)	431	44.7			
Agel et al. (2007b)	?	? (501)	6,639	48.3			
Professional							
Emery et al. (1999)	?	7050 (?)	G/A Only: 617 1995–1997: 272	60.6			
Jorgenson & Schmidt-Olsen (1986)	16–34	266 (14)	189	55.0			
Molsa et al. (1997)	18–37	? (7)	Overall: 189 FNL: 134 DIV: 55	54.5			
Pettersson & Lorentzon (1993)	Mean: 25	Mean: 22–25 players/ season (1)	376	36			
Biasca et al. (1995)	?	? (21)	SNT Only: 114			60.1	
Groger (2001)	14–19	Mean: 22/ team (?)	147	64.6		30.27	
Lorentzon et al. (1988a)	17–29	24–25 players/ season (1)	Overall: 95 FL Only: 29			71.8	
Lorentzon et al. (1988b)	19–33	22–25 players/ team (1)	Overall: 19 FL Only: 17			125.0	

A-E = athlete-exposures; CO = concussion only; DIV: Finnish Division I Men's League (second highest playing league in Finland); FFS: National Hockey Team.

Injuries in Defensive players				Injuries in Goalkeepers			
Total No. of Injuries (%)	Per 1,000 Player-Games	Per 1,000 Player-hr	Per 1,000 AEs	Total No. of Injuries (%)	Per 1,000 Player-Games	Per 1,000 Player-hr	Per 1,000 AEs
		134				0	
1: 34.7 2: 32.6 36.4				1: 4.8 2: 6.1			
36.4		151		4		16	
34.2		101.5		6.0			
HFS: 43.9 FFS: 36.8 31.8			9.9	10.0			6.84
32.7			5.0	6.2			2.7
28.7	18.14			5.3	20.16		
41.2				14.0			
40.8				9.6			
28.9				5.5			
37.0				8.0			
31.2				5.8			
57				7			
		43.7				4.1	
29.9		14.02		5.5		2.54	
		107.8				39.2	
		50.0				0.0	

full face shield; FL = facial lacerations; FNL = Finish National League; G/A = groin/abdominal; HFS = half face shield; SNT = Swiss

Table 28.3 Percent comparison of injury location among junior, college, and professional ice hockey players.

Injuries	Study [total no. of injuries]											
	Junior (%)				College (%)							
	Stuart & Smith (1995) [142]	Stuart et al. (2002) [HFN only: 113]	Pinto et al. (1999) [83]		Yohann (2001) [1,251]	Flik et al. (2005) [113]	McKnight et al. (1992) [280]	Pelletier et al. (1993) [188]	Agel et al. (2007a)		Agel et al. (2007b)	
			F	D					[Pr, 167]	[G, 264]	[Pr, 167]	[G, 264]
Head/Neck	3	0.8	8.5	4.2	10.0	19	11.0	10.6	16.2	25.4	10.3	15.4
Face	26	58.4	23.4	29.2	10.7			17.6 (+ear and jaw)				
Teeth		14.2										
Eye		12.4										
Concussion		13.3										
Spine/trunk					5.8	9			26.4	11.4	26.4	14.3
Upper back			2.1	8.3				4.8				
Lower back	6											
Chest/ribs	2		4.3	0	1.9		7.1					
Abdomen	1				0.9							
Upper Extremity							11.8		22.2	30.3	24.9	34.4
Shoulder	20		12.8	12.5	12.0	15	18.2	14.9				
Arm			2.1	0	1.5			3.7				
Elbow	2		6.4	0	4.5							
Forearm			2.1	0	1.8			6.9				
Wrist	1		0	4.2	5.1	7						
Hand/Fingers	5		6.4	16.7	6.1							
Lower Extremity									31.1	31.8	35.9	34.3
Pelvis/hips	14		6.4	4.2	3.3	9		6.4 (+abdomen)				
Thigh/groin	4		12.8	12.5	15.4		20.4	9.0				
Knee	6		8.5	4.2	8.8	22	15.7	18.6				
Leg	1		2.1	0	5.4		7.5	1.1				
Foot/toes	5		2.1	0	2.6	12		1.6				
Ankle	4		0	4.2	4.5		8.2	3.2				
Other						7			4.2	1.1	2.5	1.6

D = defensive players; F = forwards; FL = facial lacerations that did not result in time loss to participation; G = game; HFN = head, face, neck; NHL = National

Study [total no. of injuries]								
Professional (%)								
Jorgenson & Schmidt-Olsen (1986) [189]	Pettersson & Lorentzon (1993) [376]	Biasca et al. (1995) [NHL only: 652]	Groger (2001) [147]	Lorentzon et al. (1988a) [overall: 95; FL: 29]	Lorentzon et al. (1988b) [overall: 19; FL: 17]	Biasca et al. (2005) [NLA: 254; NLB: 138]	Molsa et al. (2000) [641]	Tegner & Lorentzon (1991) [285]
	30.6		20.4	6.3	5.3	26		39.4
6.3							4	
7.4								
					5.3		4	
14.3								
	4.8		4.1					11.4
6.9				15.8	10.5			
	2.9						2	
		25	33.3	24.2		27		
6.3	5.9						10	9.2
1.5	2.9				5.3			4.0
3.7	2.7				5.3			
	1.1							
	4.8				10.5		10	
7.4	5.1				5.3		12	4.4
		41	42.2	53.7		32		
	3.5							12.1
4.8	13.8				21.1		2	
13.2	12.5				21.1		24	13.2
4.8	3.2						4	6.3
4.2	4.0				5.3		2	
	2.4				5.3		22	
19.0							4	

Hockey League; NLA = Swiss Hockey League A; NLB = Swiss Hockey League B (the two highest-ranking Swiss hockey leagues); Pr = practice.

Table 28.4 Comparison of injury rates in practices versus games in junior, college, and professional ice hockey players.

Study	Study Design	Injury Collection (source)	Age, yr	Duration of Study, (seasons)	Sample, no. of subjects (no. of teams)
Junior					
Stuart & Smith (1995)	P	Trainer, MD	17–20	3 (1990–1993)	25 (1)
Goodman et al. (2001)	P/R	Trainers, Coaches, MDs	15–20	2 (1998–2000)	Year 1: 272 (14) Year 2: 283 (14)
Stuart et al. (2002)	P	Trainer	16–21	3 (?)	282 (10)
Pinto et al. (1999)	P	Trainer, MD	16–20	1 (?)	22 (1)
College **Schick & Meeuwisse (2003)**	P/R	Team Therapist, Injury Registry (CISIR)	Mean: W: 20.9 M: 23.5	1 (1998–1999)	Overall: 261 (12) W:114 (6) M:147(6)
Yohann (2001)	P	Student Athletic Therapist, Physio-therapist	18–25	15 (1984–2001)	468 (1 team/15 seasons)
Benson et al. (2002)	P	Athletic Therapist	Median: 22	1 (1997–1998)	642 (22)
Ferrara & Schurr (1999); McKnight et al. (1992)	P	Trainer	?	3 (1987–1990)	? (7)
Flik et al. (2005)	P	Trainer	?	1 (2001–2002)	?
Agel et al. (2007a)	P	Trainer	?	4 (2000–2004)	? (43)
Agel et al. (2007b)	P	Trainer	?	16 (1988–2004)	? (501)
LaPrade et al. (1995)	P	Trainer, MD	?	4 (?)	? (1)
Professional **Jorgenson & Schmidt-Olsen (1986)**	P	Quest	16–34	2 (?)	266 (14)

No. of Injuries	Practice			Game		
	Percent of Total No. of Injuries	Injuries/1,000 Player-hr	Injuries/1,000 AEs	Percent of Total No. of Injuries	Injuries/1,000 Player-hr	Injuries/1,000 AEs
142	37	3.9		58	96.1	
1:29 2:21		1: 0.6 2:00			1:5.95 2:4.63	
HNF Only: 113					Overall/CO: NFS: 158.9/12.2 HFS: 73.5/8.2 FFS: 23.2/2.9	
74	23	4		62	Ex/Pre: 303 L/Post: 83	
W: 66 M: 161			W: 3.03 M: 2.27			W: 10.43 M: 22.40
1251		3.2			104.2	
HFS: 41 FFS: 38	HFS: 17.1 FFS: 0			HFS: 82.9 FFS: 100		
280	35		2.52	65		14.73
113			2.2			13.8
Pr: 167 G: 264			Overall: 2.5 Pre: 4.2 In: 2.3 Post: 0.7			Overall: 12.6 Pre: 9.6 In: 12.8 Post: 10.6
Pr: 1,966 G: 4,673			Overall: 1.96 Pre: 5.05 In: 1.94 Post: 1.27			Overall: 16.27 Pre: 11.59 In: 16.72 Post: 11.91
FL Only: 16		0.10			14.9	
189	30	1.5		70	38.0	

(*continued*)

Table 28.4 (*continued*)

Study	Study Design	Injury Collection (source)	Age, yr	Duration of Study, (seasons)	Sample, no. of subjects (no. of teams)
Molsa et al. (1997)	P	MD	18–37	1 (1988–1989)	? (7)
Pettersson & Lorentzon (1993)	P	MD	Mean: 25	4 (1986–1990)	Mean: 22–25 players/season (1)
Biasca et al. (1995)	P	Injury registry	?	NHL: 1 (1989–90) RR: 5 (1984–90) CAHA: 3 (1988–91) SNT: 2 (1989–91)	NHL: ?/(21) RR: ?/(1) CAHA: ?/(?) SNT: ?/(1)
Groger (2001)	P	MD	14–19	11 (1986–95)	? (?)
Lorentzon et al. (1988a)	P	MD	17–29	3 (1982–85)	24–25 players/season (1)
Lorentzon et al. (1988)b	P	MD	19–33	1 1984–1985)	22–25 players/season (1)
Biasca et al., 2005	P	Injury registry	?	2 (1996–1998)	? (?)
Molsa et al. (1997)	P	MD	?	5 (1976–1979; 1988–1989; 1992–1993)	1976–1979: 17 players/team (7) 1988–1989: 22 players/team (5) 1992–1993: 22 players/team (3)
Tegner & Lorentzon (1991)	P	MD	?	1 (1988–89)	?(12)
Tegner & Lorentzon (1996)	R/P	MD	?	R: ? (?) P: 4 (1988–92)	R: 265 (11) P: 480 (14)

AE = athlete-exposure; CAHA = Canadian Amateur Hockey Association; CO = concussion only; DIV = Finnish Division I Men's League G = games; HFS = half face shield; HNF= head, neck, face; In = in-season; L = league; M = men; NFS = no face shield; NHL = National P = prospective; PO = play-off; Post = post-season; Pr = practices; Pre = preseason; R = retrospective; RR = one anonymous NHL team;

No. of Injuries	Practice			Game		
	Percent of Total No. of Injuries	Injuries/1,000 Player-hr	Injuries/1,000 AEs	Percent of Total No. of Injuries	Injuries/1,000 Player-hr	Injuries/1,000 AEs
Overall: 189 FNL: 134 DIV: 55		Overall: 1.5 FNL: 1.4 DIV: 1.6			Overall: 54 FNL: 66 DIV: 36	
376	31.1	5.4		68.9	202.2	
NHL: 652 RR: 207 CAHA: 1,523 SNT: 114	NHL: 11 RR: 14 CAHA: 27 SNT: 25			NHL: 89 RR: 86 CAHA: 73 SNT: 75	NHL: 129 CAHA: 480 SNT: 107	
147					46.8	
Overall: 95 FL Only: 29	24.2	1.4		75.8	78.4	
Overall: 19 FL Only: 17					Overall: 79.2 FL Only: 70.8	
NLA: 254 NLB: 138	15			L: 78 Friendly: 3	NLA: 42 NLB: 21	
Overall: 641 76–79: 367 88–89: 144 92–93: 130	25	1.5		75	1976–1979: 54 1988–1989: 55 1992–1993: 83	
285	26			74	53	
R: CO – 87 P: All – 805 CO – 52					P: CO—6.5	

(second highest playing league in Finland); Ex = exhibition; FFS = full face shield; FL = facial laceration; FNL = Finish National League; Hockey League; NLA = Swiss Hockey League A; NLB = Swiss Hockey League B (the two highest-ranking Swiss hockey leagues); SNT = Swiss National Team; T = tournament; W = women.

Table 28.5 Percent comparison of injury onset in junior, college, and professional ice hockey players.

Study	Study Design	Duration of Study, no. of seasons (yr)	Sample, no. of subjects (no. of teams)	No. of Injuries	Injury Onset	
					Trauma (%)	Overuse (%)
Junior						
Pinto et al. (1999)	P	1 (?)	22 (1)	74	86.5	13.5
College						
Yohann (2001)	P	15 (1984–2001)	468 (1 team/15 seasons)	1,251	82	18
McKnight et al. (1992)	P	3 (1987–1990)	? (7)	280	87.5	12.5
Professional						
Pettersson & Lorentzon (1993)	P	4 (1986–1990)	Mean: 22–25 players/season (1)	376	84.6	15.4
Lorentzon et al. (1988a)	P	3 (1982–1985)	24–25 players/season (1)	Overall: 95 FL only: 29	80	20
Lorentzon et al. (1988b)	P	1 (1984–1985)	Mean: 22–25 players/season (1)	Overall: 19 FL only: 17	100	0
Tegner & Lorentzon (1991)	P	1 (1988–1989)	? (12)	285	85.4	14.6

FL = facial laceration; P = prospective; R = retrospective.

46%. Agel et al (2007b) showed an equal distribution of injury in the second and third periods (36%).

Time of Season

Few studies reported incidence according to time of season. Findings from three studies (Pinto et al. 1999; Agel et al. 2007a, 2007b) are reported in Table 28.4. Agel et al. compared male (Agel et al. 2007b) and female (Agel et al. 2007a) college injury rates and found that both sexes reported high preseason practice injury rates (5 and 4 injuries per 1,000 AEs, respectively) as compared with in-season (2 injuries per 1,000 AEs for both) and postseason practice (1 injury per 1,000 AEs for both) injury rates. Agel et al. (2007b) suggested that higher injury rates during the preseason period may result from competition between teammates fighting for starting positions and more intrasquad scrimmages. Agel et al. (2007b, 2007a) also found that both male and female college players reported higher regular-season game injury rates (17 and 13 injuries per 1,000 AEs, respectively), which again can be attributed to a higher level of intensity, aggression, and opposition experienced during games. Pinto et al. (1999) observed higher exhibition and preseason game injury rates (303 injuries per 1,000 player-hours) over regular-season and postseason games (83 injuries per 1,000 player-hours) in a Junior A hockey team, but attributed the findings to the team playing four exhibition games against two Russian teams that were bigger and older national-level–caliber players.

What Is the Outcome?

Injury Type

Hockey players are in constant motion, circumstances can change rapidly, and all five players have both offensive and defensive roles during each shift (Molsa et al. 2000). This can expose them to multiple risks, a wide variance of grievances, and different mechanisms of injury. For instance, player contact at high speeds with other players, hockey equipment, and the arena itself can result in injuries ranging from dental injuries, concussions, fractures, lacerations, wounds, contusions, strains, sprains, dislocations, and catastrophic injuries.

Only 14 of 50 studies reported injury type. A percent comparison of these studies is shown in Table 28.7. In six studies (Lorentzon et al. 1988a, 1988b; McKnight et al. 1992; Pettersson & Lorentzon 1993; Molsa et al. 2000; Yohann 2001) contusions were the most common type of injury sustained by players across all levels of competition (29–46%), and the second most common type of injury in two others (29–39%) (Molsa et al. 1997; Pinto et al. 1999). Strains and sprains were the next most prevalent type of injury (3–53%) (Biasca et al. 1995; Stuart & Smith 1995; Molsa et al. 1997). One study found that adductor muscle strains were the most prevalent in the National Hockey League (NHL), with one fourth of all groin/abdominal injuries being recurrent (Emery et al. 1999). Eight studies (Jorgensen & Schmidt-Olsen 1986; Lorentzon et al. 1988a; Pettersson & Lorentzon 1993; Molsa et al. 1997; Yohann 2001; Schick & Meeuwisse 2003; Agel et al. 2007a, 2007b) found a majority of sprains either specific to the knee or the acromioclavicular joint in the shoulder or both. Lacerations were the most common type of injury to the face (Stuart et al. 2002).

Other types of injury, however, did not reveal obvious trends across types or levels of participation. For instance, Tegner and Lorentzon (1991) noted lacerations as the most common type of injury sustained by Swedish elite hockey players (27%) in one study, whereas Lorentzon et al. reported low percentages [3% (1988b) and 5% (1988a)] in another. Variations in injury rates can be attributed to differences in the definition of injury (e.g., time loss versus no time loss), variance in rules and regulations with respect to levels of body-checking, types of protective equipment mandated, ice surface size, levels of intensity, and skill.

When analyzed by level of play, the most common injury types were laceration/wounds (15–70%) and contusions (4–30%) at the junior level (Pinto et al. 1999; Stuart & Smith 1995; Stuart et al. 2002); contusions (21–33%) at the college level (McKnight et al. 1992; Pelletier et al. 1993; Yohann, 2001); and contusions (15–46%) and strains/sprains (8–53%) at the professional level (Jorgensen &

Table 28.6 Comparison of injury rates among junior, college, and professional ice hockey players by period.

Study	Age, yr	Sample, no. of subjects	No. of Injuries	First Period		
				Percent of Total No. of Injuries	Injuries/1,000 Player-hr	Injuries/ 1,000 AEs
Junior						
Pinto et al. (1999)	16–20	22 (1)	74	20.5		
College						
Schick & Meeuwisse (2003)	Mean: W: 20.9 M: 23.5	Overall: 261 (12) W:114 (6) M:147(6)	W: 66 M: 161	W: 6.90 M: 34.95		
Yohann (2001)	18–25	468	1251	24.3		
Flik et al. (2005)	?	?	113	36.5		15.1
Pelletier et al. (1993)	19–25	Mean: 19 players/game	188	27.1		
Agel et al. (2007b)	?	?	6,639	27.5		
Professional						
Pettersson & Lorentzon (1993)	Mean: 25	22–25 players/season	376	20		
Lorentzon et al. (1988a)	17–29	24–25 players/season	Overall: 95 FL only: 29	27		
Lorentzon et al. (1988b)	19–33	22–25 players/season	Overall: 19 FL only: 17			
Molsa et al. (2000)	?	1976–1979: 17 players/team ?× 7 1988–1989: 22 players/team × 5 1992–1993: 22 players/team × 3	Overall: 641 1976–1979: 367 1988–1989: 144 1992–1993: 130	1988–1989 only: 24		
Tegner & Lorentzon (1991)	?	?	285	31		
Tegner & Lorentzon (1996)	?	R: 265 P: 480	R: CO—87 P: All—805 CO—52	P: CO—30		

AE = athlete-exposure; CO = concussion only; FL = facial lacerations; M = men; P = prospective; R = retrospective; W = women.

Schmidt-Olsen 1986; Lorentzon et al. 1988a, 1988b; Tegner & Lorentzon 1991; Pettersson & Lorentzon 1993; Biasca et al. 1995; Molsa et al. 1997, 2000).

Concussions

Concussions are frequent at all levels of competition and typically produce transient neurologic signs and symptoms that largely reflect functional disturbance rather than structural brain damage. This creates a great burden of injury, which may result in prolonged time loss from participation (Schick & Meeuwisse 2003). Although most signs and symptoms tend to resolve over time when concussive injuries are recognized and managed appropriately, all of them have the potential to be catastrophic (Cantu 1997). A comparison across all studies is difficult because of differences in injury

Second Period			Third Period		
Percent of Total No. of Injuries	Injuries/1,000 Player-hr	Injuries/ 1,000 AEs	Percent of Total No. of Injuries	Injuries/1,000 Player-hr	Injuries/ 1,000 AEs
33.3			46.2		
W: 51.72 M: 33.98			W: 41.38 M: 31.07		
43.8			31.9		
36.5		15.1	27.0		11.2
35.6			26.6		
35.5			35.5		
31.5			21.5		
30			36		
FL only: 65			FL only: 35		
1988–1989 only: 30			1988–1989 only: 42		
38			28		
P: CO—54			P: CO—16		

definitions, reporting mechanisms, and study designs. The following highlights some important findings from the studies selected for review:

- Incidence of concussion ranged from 0–26% for all studies that compared injury types (Table 28.7).
- Goodman et al. (2001) investigated concussion rates in the British Columbia Junior Hockey League and reported annual concussion rates of 6 injuries per 1,000 game-hours in 1998–1999 and 5 injuries per 1,000 game-hours in 1999–2000; higher proportions of concussion were sustained by forwards (56–58%) and during games (90%).
- Schick and Meeuwisse (2003) observed that the most common type of injury in male and female Canada West University hockey players was concussion, which also resulted in the most time loss from unrestricted participation.

Table 28.7 Percent comparison of injury types among junior, college, and professional ice hockey players.

Study	Age, yr	Total No. of Injuries	Dental (%)	Concussion (%)	Fracture (%)
Junior					
Stuart & Smith (1995)	17–20	142			
Stuart et al. (2002)	16–21	HFN: 113	6.2	9.8	4.4
Pinto et al. (1999)	16–20	F/D 74		2.1/0	8.5/4.2
College					
Yohann (2001)	18–25	1251		6.6	4.0
McKnight et al. (1992)	?	280		2.1	5.7
Pelletier et al. (1993)	19–25	188		7.5	10.2
Professional					
Jorgenson & Schmidt-Olsen (1986)	16–34	189		25.9	7.4
Molsa et al. (1997)	18–37	Overall: 189 FNL: 134 DIV: 55			8.0
Pettersson & Lorentzon (1993)	Mean: 25	376	2.2	3.8	2.5
Biasca et al. (1995)	?	NHL: 652 RR: 207 CAHA: 1523 SNT: 114		NHL: 3 RR: 4 CAHA: 2	NHL: 10 RR: 11 CAHA: 8
Lorentzon et al. (1988a)	17–29	95		5.3	13.2
Lorentzon et al. (1988b)	19–33	Overall: 19 FL Only: 17			10.5
Molsa et al. (2000)	1976–1979: 17 players/team × 7 1988–1989: 22 players/team × 5 1992–1993: 22 players/team × 3	Overall: 641 1976–1979: 367 1988–1989: 144 1992–1993: 130			1976–1979: 15 1988–1989: 7 1992–1993: 10
Tegner & Lorentzon (1991)	?	285	5.3	2.8	9.1

CAHA = Canadian Amateur Hockey Association; D = defensive players; DIV = Finnish Division I Men's League (second highest playing Hockey League; RR = one anonymous NHL team; SNT = Swiss National Team; TMJ = temporomandibular joint.

- Flik et al. (2005) found that concussions were the most frequently sustained injury among American Division I Collegiate ice hockey players (19%); this injury was responsible for nearly one quarter of all game-related injuries.
- Benson et al. (2002) studied risk factors for concussion severity among Canadian University male ice hockey players and revealed a concussion incidence of 1.55 per 1,000 AEs, thus averaging three to four concussions per team during any given season.
- Jorgenson and Schmidt-Olsen (1986) found concussions to be the most frequent type of head injury in both forward (17%) and defensive (14%) Danish elite hockey players.
- Tegner and Lorentzon (1996) reported a concussion incidence of 6.5 per 1,000 game-hours in the Swedish Elite League; they further suggested that

Laceration/ Wound (%)	Contusion (%)	Strain (%)	Sprain (%)	Dislocation (%)	Other/Unknown (%)
24	18	25	16		
69.9	3.5		1.8 (TMJ)		4.4
14.9/20.8	29.8/29.2		36.2/41.7		8.5/4.2
9.9	28.5	17.1	20.9	With subluxation: 6.3	6.6
8.9	32.5	14.6	29.6	3.2	
13.0	21.0	11.3	31.0		5.9
		7.9	14.3		44.4
11.2	38.8	39.7			2.3
26.0	43.4	9.5	12.0		
CAHA: 10	NHL: 15 RR: 21 CAHA: 35	NHL: 25 RR: 28 CAHA: 18	NHL: 20 RR: 30 CAHA	NHL: 3 CAHA: 4	
2.6	32.9	17.1	22.6		1.3
5.3	36.8	15.8	31.6		
1976–1979: 28 1988–1989: 17 1992–1993: 10	1976–1979: 41 1988–1989: 46 1992–1993: 46	1976–1979: 30 1988–1989: 42 1992–1993: 53		1976–1979: 1 1988–1989: 2 1992–1993: 3	
27.4	18.2	24.2	3.2	9.8	

league in Finland); F = forwards; FL = facial lacerations; FNL = Finish National League; HNF = head, neck, face; NHL = National

at least 20% of elite ice hockey players will sustain a concussion during their ice hockey career.
- Wennberg and Tator (2003) observed significant increases in concussion rates that coincided with increases in mean player heights and weights

Time Loss

Time loss from participation is commonly used as a marker of injury severity. Table 28.8 shows a comparison of injury severity according to time loss from injury or hospitalization for 15 studies. Time loss was reported according to lost sessions, days, and athlete-exposures. Nonuniform injury definitions made it difficult to make comparisons across the studies. Across all levels of competition, the majority of injuries resulted in ≤7 days of time loss (35–85%), with most studies classifying these as minor or mild in terms of severity. It is important to remember that unexpected and extended

Table 28.8 Comparison of injury severity among junior, college, and professional ice hockey players.

Study	Study Design	Age, yr	Time Frame	No. of Injuries	Time Loss	Hospitalization
Junior						
Stuart & Smith (1995)	P	17–20	1990–1993	142	Mild (≤3 days): 58% Moderate (4–14 days): 36% Severe (*): 6%	Surgery: 2.1%
Pinto et al. (1999)	P	16–20	?	74	<1 day: 85% >1 day: 12% 28 days: 3%	
College						
Schick & Meeuwisse (2003)	R/P	Mean: W: 20.9 M: 23.5	1998–1999	W: 66 M: 161	W/M (no. of sessions missed) 1: 1.18/0.91 sessions per 1000 A-E 2–7: 4.95/4.57 sessions per 1000 A-E 8–14: 1.30/1.83 sessions per 1000 A-E >14: 0.35/1.88 sessions per 1000 A-E	
Yohann (2001)	P	18–25	1984–2001	1251	No time lost: 62% Mild (≤1 game): 11.9% Moderate (<1 wk): 17.8% Moderate/Severe (<3 weeks): 5.3% Severe (≥3 wk): 3.5%	
Benson et al. (2002)	P	Median: 22	1997–1998	HFS: 41 FFS: 38	HFS/FFS Mild (<1 session): 41.5%/65.8% Moderate (1–7 sessions): 41.5%/31.6% Severe (>7 sessions): 17.0% / 2.6%	
Ferrara & Schurr (1999); McKnight et al. (1992)	P	?	1987–1990	280	Minor (0–7 days): 59.6% Moderate (8–21 days): 25.7% Major (≥22 days): 14.6 %	

Professional					
Emery et al. (1999)	R	?	1991–1997	Groin/ abdomen only: 617	Overall: 14.46 sessions Groin: 6.59 sessions Abdomen: 10.59 sessions
Emery & Meeuwisse (2001)	P	?	1998–1999	Groin/ abdomen only: 204	Overall: 11.42 sessions
Molsa et al. (1997)	P	18–37	1988–1989	Overall: 189 FNL: 134 DIV: 55	FNL/DIV: Minor (0–7 days): 80.0%/63% Moderate (8–28 days): 16%/28% Major (>28 days): 4%/9%
Pettersson & Lorentzon (1993)	P	Mean: 25.0	1986–1990	376	Minor (≤7 days): 34.6% Moderate (8–30 days): 3.7% Major (>30 days): 1.1%
Lorentzon et al. (1988a)	P	17–29	1982–1985	95	Minor (≤7 days): 72.6% Moderate (8–30 days): 19.0% Major (>30 days): 8.4%
Biasca et al. (2005)	P	?	1996–1997	NLA: 254 NLB: 138	Minor (<7 days): 40.0% Moderate (7–30 days): 50.0% Major (>30 days): 10.0%
Molsa et al. (2000)	P	?	1976–1979 1988–1989 1992–1993	1976–1979: 367 1988–1989: 144 1992–1993: 130	76–79/88–89/92–93: Minor (0–7 days): 60.0%/81%/80% Moderate (8–28 days): 30.0%/15%/15% Major (>28 days): 10.0%/4%/5%
Tegner & Lorentzon (1991)	P	?	1988–1989	285	Minor (<7 days): 61.1% Moderate (8–30 days): 22.3% Major (>30 days): 8.8%

DIV = Finnish Division I Men's League (second highest playing league in Finland); FFS = full face shield; FNL = Finish National League; HFS = half face shield; M = men; NLA = Swiss Hockey League A; NLB = Swiss Hockey League B (the two highest-ranking Swiss hockey leagues); P = prospective; R = retrospective; W = women.

periods of time loss from participation can stem not only from physical setbacks, but also from motivational and psychological barriers.

Clinical Outcome

Catastrophic Injury

Catastrophic sport injuries may include permanent, severe functional brain or spinal cord disability, transient brain or spinal cord disability, systemic failure as a result of exertion while participating in a sport (Cantu & Mueller 2008), functional loss of an organ, removal of an organ, or loss of life. Cantu and Mueller (2008) observed that although the absolute number of catastrophic ice hockey injuries is low, fatality and catastrophic rates in American high schools (3.11 fatalities per 100,000 participants) and colleges (11.55 fatalities per 100,000 participants) are higher than in other sports, such as basketball (0.05 and 0.81 fatalities per 100,000 participants), wrestling (0.93 and 0.92 fatalities per 100,000 participants), and football (1.76 and 6.96 fatalities per 100,000 participants). An analysis of head injuries presenting to an Emergency Department in Alberta, Canada, attributed one third of all sport-related head injuries to the sport of ice hockey (Kelly et al. 2001).

A comparison of reported catastrophic injury rates is shown in Table 28.9. Only 7 (Horns 1976; Molsa et al. 1999; Pashby et al. 1975; Pashby 1977; Tator et al. 1997; Tegner & Lorentzon 1991, 1996) of 50 studies met inclusion criteria and reported catastrophic ice hockey injury rates.

Stuart et al. (2002) found that the risk of sustaining an eye injury was five times greater for players wearing no facial protection as compared with those who wore at least partial protection. Although full face shields have been shown to reduce dental, facial, and ocular injuries, many players still continue to wear half shields (visors) or no face shields (LaPrade et al. 1995; Benson et al. 1999). Pashby extensively studied eye injuries occurring among Canadian ice hockey players (Pashby et al. 1975; Pashby 1977, 1979a, 1979b, 1985, 1987, 1981). The frequency of blindness reported in two studies (Pashby et al. 1975; Pashby 1977) was 9 of 56 cases (1974–1975) and 5 of 29 cases (1976–1977) among 16-to-20-year-olds. In adult players ⩾20 years of age, 13 of 69 cases resulted in blindness in 1974–1975 and 5 of 33 in 1976–1977. Horns (1976) also analyzed ice hockey–related eye injuries in the United States and reported a frequency of blindness of 7 of 47 cases. No eye protection was worn in all cases in which blindness occurred.

Spinal injuries usually result from pushing or checking from behind, which causes an impact with the boards or sometimes with other players (Pashby 1981; Molsa et al. 1999; Tator et al. 1997). The impact of the helmet against opposition transmits an axial compressive load to a neutral or slightly flexed cervical spine, which may cause a vertebral burst fracture or dislocation (Cunningham 1995; Tator et al. 1997). A 1987 review of neck injuries in ice hockey also observed sliding into the boards as a common mechanism for cervical spine injuries (Tator 1987). Three studies (Molsa et al. 2003; Tator et al. 1997; Tegner & Lorentzon, 1991) presented injury rates for spinal injuries. Tator et al. (1997) reported 8 fatalities out of 245 subjects, and 108 permanent spinal injuries out of 207 subjects taken from information gathered from Canada's Committee on Prevention of Spinal Cord Injuries Due to Hockey Registry (SportSmart Canada). Tegner and Lorentzon (1991) noted 1 case of tetraplegia (or four-limb paralysis) out of 285 Swedish professional hockey players. Molsa et al. (2003) collected information on patients with ice hockey–related spinal cord injuries in Finland and Sweden from 1980 to 1996 and found 10 cases of tetraplegia and 6 cases of paraplegia. One study (Tegner & Lorentzon 1996) reported a case of recurrent concussion leading to permanent brain damage, confirmed by neuropsychological testing, and resulting in the following functional deficits: concentration problems, irritability, and impaired memory.

What Are the Risk Factors?

Those who promote and regulate health and safety need to understand the ways people think about and respond to risk (Slovic 1987). The way science estimates risk is very different from the way the

Table 28.9 Comparison of catastrophic injury rates among junior, college, and professional ice hockey players.

Study	No. of Subjects	Age, yr	Time Frame	Injury Type	Condition	Absolute No.
Molsa et al. (1999)	?	14–33	1980–1996	Spinal cord injury	Tetraplegia Paraplegia	TP: 10/16 PP: 6/16
Pashby et al. (1975)	?	16–20 Over 20	1974–1975	Eye injury	Blindness	56, blind: 9 69, blind: 13
Tegner & Lorentzon (1991)	285	?	1988–1989	Cervical spine injury	Tetraplegia	1/285
Tegner & Lorentzon (1996)	R: 265 P: 480	?	R:? P: 1988–1992	Brain injury	Permanent brain damage	P: 1/480
Horns (1976)	47	?	Case series	Eye injury	Blind	47, blind:7
Pashby (1977)	?	16–20 Over 20	1976–1977	Eye injury	Blindness	29, blind: 5 33, blind: 5
Tator et al. (1997)	147/241	11–20	Case series	Cervical spine injury	Fatality Permanent injury	F: 8/241 PI: 108/207

F = fatality; P = prospective; PI = permanent injury; PP = paraplegia; R = retrospective; TP = tetraplegia.

public assesses risk; although lay people may lack specific information about a hazard, their conceptualization of risk reflects concerns that are typically omitted from expert risk assessments (Slovic 1987). The public generally believes that the characteristics of the sport itself predispose athletes to injury. That is, the risk of sustaining an injury is generally accepted as an inherent part of the game. Identification of risk factors can help with the development of injury-prevention strategies. Trends and patterns of injury were examined in the selected studies reporting risk. These risk factors can be classified as intrinsic or extrinsic.

Intrinsic Factors

Physical Characteristics

Age, height, and weight were commonly found to be risk factors for injury across several studies. Aside from physiological growth with age, changes to rules and regulations (e.g., removal of two-line passes), technological advancements in equipment and environment, enhanced nutritional supplements and training techniques have all increased the speed of the game and size of the participants. Findings from Molsa et al. (2000) support this as the rate of injury per player-hours during games increased 1.5 times from the 1970s to the 1990s (95% confidence interval, 1.2–1.9; $P < 0.001$) among Swedish elite players.

Strength can also be associated with risk of injury, as Tyler et al.(2001) observed that hip adduction strength in NHL hockey players was 18% lower in players who sustained adductor strains as compared with those who did not. Furthermore, players were 17 times more likely to sustain an injury to the adductor muscle if the adductor strength was <80% of his abductor strength (Tyler et al. 2001).

Experience

Player experience was also a risk factor for injury. Emery and Meeuwisse (2001) found NHL veteran players (mean, 25 years old) were six times more likely to experience groin injuries compared with rookies (mean, 18 years old) during training camp. Veteran players were also four times more likely to suffer an injury during regular season of play. Although experience can be related to age, Emery and Meeuwisse (2001) suggested an increased risk related to the relationship between level of sport specific training in the off-season and the years of NHL experience (i.e., rookies may have been performing more sport specific training in the off-season to prepare for training camp).

Previous Injuries

In several studies, players that suffered from previous injuries were likely to be at greater risk for reinjury. New injuries can result from stress, overcompensation or guarding, and lack of confidence; whereas reinjuries can result from inadequate rehabilitation, fitness deterioration during injury, underestimation of the severity of the primary injury, premature return to sport, and persistent instability (Dryden et al. 2000). At an NHL training camp, those who reported previous groin injuries were at 2.4 to 2.6 times the risk of reinjury in training camp than those who reported no previous history (Emery & Meeuwisse 2001).

Extrinsic Factors

Exposure

Risk was also influenced by game versus practice exposure, collision rates, and playing time. For example, Junior A hockey players were also 7 times more likely to experience a muscle strain in games versus practice (Stuart & Smith 1995), whereas Swedish elite players were 29 times more likely to sustain an injury during games (Pettersson & Lorentzon 1993). This evidence may reflect a higher intensity characteristic in games, with more frequent and forceful body contact and more stick violations (Pettersson & Lorentzon 1993).

Sport Specific Training

Emery and Meeuwisse (2001) revealed that players with low levels of off-season sport specific training were found to be a risk for groin injuries in NHL professional hockey players. They found that players who reported training for <18 sport specific sessions during the off-season were more than 3 times the risk of sustaining a groin or abdominal injury during training camp. Also, players who reported training <12 sport specific sessions in the month preceding training camp were at 3 times the risk of injury during training camp compared with those who reported training <12 sessions (Emery & Meeuwisse 2001).

Equipment

Facial protection attached to helmets remain an issue at all levels of competition. Several studies have reported lower injury rates to the head, face, dentition, and eyes when full facial protection is worn (Benson et al. 1999; Biasca et al. 2005; Groger 2001; LaPrade et al. 1995; Lorentzon et al. 1988a; McKnight et al. 1992; Molsa et al. 1997; Schick & Meeuwisse 2003). In many leagues and organizations, however, implementation of mandatory facial protection is still not enforced. Youth, high school, junior (most leagues), and women's hockey are the only ones. Benson et al. (1999, 2002) prospectively investigated the risk of injury among Canadian intercollegiate ice hockey players wearing half versus full face shields. The major findings of two studies on this topic area were as follows:

- the risk of sustaining any head/facial injury while wearing a half shield is 2.5 times the risk of sustaining the same injury while wearing full facial protection (Benson et al. 1999, 2002).
- the risk of sustaining a facial laceration for players wearing a visor is almost 3 times greater than for athletes wearing full face shields (relative risk [RR], 2.8; 95% confidence interval [CI], 1.9–4.1) (Benson et al. 1999, 2002).
- the risk of sustaining a dental injury (tooth fracture) is at least 2.2 times greater for players wearing half shields compared to full facial protection (RR, 11.37; 95% CI, 2.2–57.7) (Benson et al. 1999, 2002).
- the risk of sustaining a neck injury or concussion is not significantly different for players wearing full versus half shields (Benson et al. 1999, 2002).
- overall injury rates were not significantly different for players wearing full facial protection versus partial facial protection (visors) (Benson et al. 1999, 2002).
- players who wore half face shields missed significantly more practices and games per concussion (2.4 times) than players who wore full face shields (4.07 sessions; 95% CI, 3.48–4.74 vs. 1.71 sessions; 95% CI, 1.32–2.18, respectively) (Benson et al. 2002).
- significantly more playing time was lost by players wearing half shields during practices and games, and this did not depend on whether the athletes were forwards or defensive players, rookies or veterans, or whether the concussions were new or recurrent (Benson et al. 2002).
- players who wore half face shields and no mouth guards at the time of concussion missed significantly more playing time (5.57 sessions per concussion; 95% CI, 4.40–6.95) than players who wore half shields and mouth guards (2.76 sessions per concussion; 95% CI, 2.14–3.55) (Benson et al. 2002).
- players who wore full face shields and mouth guards at the time of concussion lost no playing time as compared with 1.80 sessions lost per concussion (95% CI, 1.38–2.34) for players wearing full face shields and no mouth guards (Benson et al. 2002).

Although the benefits of mouthguard use in protecting athletes from dental injury is well supported in the literature (Newsome et al. 2001; Wisniewski et al. 2004; ADA Council on Access & ADA Council on Scientific Affairs, 2006; Cohenca et al. 2007), controversy exists as to whether mouthguard use can reduce athletes' risk of concussive head injuries (McCrory 2001; Winters 2001; Wisniewski et al. 2004). Mouth guards are typically composed of a thermoplastic material, ethylene vinyl acetate, designed to fit over occlusal surfaces of the maxillary teeth and gingivae (ADA Council on Access & ADA Council on Scientific Affairs 2006). The purpose of wearing these devices is to distribute and dissipate forces transmitted during impact to reduce the risk and severity of injury to the teeth, maxilla, mandible, lip, gingivae, tongue, and mucosa (ADA Council on Access & ADA Council on Scientific Affairs 2006). At this time, there is no valid scientific evidence of a significant association between mouth guard use and reduced concussion risk. There is also no evidence of increased risk of injury, but there is evidence to support the use of mouth guards for dental protection.

What Are the Inciting Events?

Mechanism of Injury

Injury risk in ice hockey is high because of the innate characteristics of the sport itself, which include peak velocities produced by 6 oz of solid frozen rubber pucks reaching 192 km/hr in professional hockey and 144 km/hr in senior recreational hockey; maximal impact forces from the puck at 1,250 lb; potential forces on impact considering skating speeds of 32 to 48 km/hr depending on skill level; sliding speeds of up to 24 km/hr; cervical spine compression forces reported at approximately 5,000 N, with mechanical stimulation of head to board impact of 1.8 m/s; rigid fiberglass, graphite, or wooden hockey sticks reaching angular velocities of 20 to 40 rad/sec; and high-impact collisions between players, ice surface, and goal posts (Bishop & Wells 1989; Pforringer & Smasal 1987; Sim & Chao 1978). Board contact has also been a concern for many years as a direct or indirect mechanism of injury presenting with inconsistencies in board construction, mounting, presence of various sizes of ledges and other hazards (Ferrara & Schurr 1999) (Figure 28.1).

Table 28.10 shows a percent comparison of mechanism of injury among ice hockey players in 21 studies. Irrespective of competition level, all studies except two (Pinto et al. 1999; Stuart et al. 2002) reported body-checking and collisions as causing the highest percentage of injuries in hockey players (25–90%). Agel et al. (2007a, 2007b) and Benson et al. (2002) also found body-checking and collisions to be a causative factor for concussion injury. Molsa et al. (1999) revealed that checking from behind was the primary mechanism for spinal cord injuries. Stuart et al. (2002) and Pinto et al. (1999) observed a higher percentage of injuries resulting from stick contact (36% and 16%, respectively); however, both studies looked at head, neck, and facial injuries only. Although skate blades have the potential to cause considerable injury, six (Benson et al. 1999, 2002; Pinto et al. 1999; Stuart & Smith 1995; Yohann, 2001; Flik et al. 2005) of 10 studies that reported skate contact as a mechanism of injury found it to have the lowest percentage of causing injury (1–5%).

Injury Prevention

We know that many factors likely play a role before the actual occurrence of an injury. It is important to identify and understand such contributing factors before effective preventive strategies can be developed. The high intensity in which the sport of ice hockey is played frequently results in forceful impacts among players and with hockey sticks, pucks, goal posts, and the boards. The inherent characteristics of the sport include high acceleration, deceleration, changing directions, shooting, passing, body checking, and a low friction ice surface, all of which make it highly unlikely to prevent all injuries. Several injury-prevention strategies have been identified in this review, however, all of which have the potential to help further protect players.

Training

Although there has been little ice hockey–specific research conducted on the effects of training and conditioning, studies in other athletic populations have shown an association between strength and flexibility, and musculoskeletal strains (Ekstrand & Gillquist 1983; Knapik et al. 1991). With respect to ice hockey players, Emery and Meeuwisse (2001) assessed the impact of increased levels of sport-specific training in the off-season and found that when the level of sport-specific training was increased from 0 to18 sessions, the estimated risk of groin or abdominal strain injury would be reduced by 50%. Tyler et al. (2001) also found that an 8- to 12-week active strengthening program consisting of progressive resistive adduction and abduction exercises, balance training, abdominal strengthening, and skating movements on a slide board proved effective in treating chronic adductor strains.

Equipment

Player equipment appears to be effective at preventing specific types of injuries. For instance, proper use of helmets, face masks, and mouth guards can reduce the incidence of facial, ocular, and dental injuries (Pashby 1985; Lorentzon et al. 1988a, 1988b; Pelletier et al. 1993; Biasca et al. 1995; Molsa et al. 1997; Ferrara & Schurr 1999; Goodman et al. 2001; Stuart et al. 2002; Stevens et al. 2006). Pashby (1977, 1979a, 1979b, 1985, 1987) noted a decrease in the incidence of the eye injuries and blindness in all groups and skill levels of the Canadian Amateur Hockey Association from the 1972–1973 season to the 1983–1984 season, all of which corresponded with an implementation of new rules, strict enforcement of penalties, and mandatory use of face masks. Lorentzon et al. (1988a, 1988b) also observed a significantly higher incidence of facial lacerations in Swedish national hockey players who failed to wear a visor. In fact, 47% to 52% (1988a and 1988b, respectively) of facial injuries would not have occurred had a visor been worn. Schick and Meeuwisse (2003) found lower facial and dental injury rates in female than in male hockey players where mandatory full facial protection is enforced in the Canada West Universities Athletic Association for women. Groger (2001) found players that did not wear full face masks suffered mostly from severe injuries to the face and had to stop playing for longer periods as compared with players who were wearing half or full visors. Unfortunately, not all injuries are preventable with the use of a face mask or visor, and high-stick infractions can still hit at a fixed angle under the visor causing injury (Lorentzon et al. 1988a; Molsa et al. 1997)

Furthermore, head injuries are still a cause for concern. Although full face makes can significantly reduce the risk of facial and eye injuries, they do not decrease the risk of concussion. If worn properly, the use of helmets can dissipate forces and might diminish the severity of traumatic brain injuries (Molsa et al. 1999), but it cannot completely prevent head injuries and concussions. Two studies (Benson et al. 1999, 2002), however, have found evidence to suggest that players who wear full face shields missed significantly fewer practices and games per concussion as compared with players who wore half face shields regardless of injury setting, previous concussion status, position, or experience level. Both studies suggested that mouth-guard use reduced concussion severity (measured by time lost from competition) (Benson et al. 1999, 2002). In addition, mouth guards worn together with full face shields can also prevent dental injuries (Agel et al. 2007b; Benson et al. 2002).

Finally, improper use of equipment can lead to injury. For example, players who do not fasten their chinstraps properly or do not wear their visors so that the visor extends down to the tip of the nose predisposes the helmet to tipping (Biasca et al. 2005). If tipping or shifting of the helmet occurs, it decreases its protective effect during impact. When chin straps are not fastened tightly enough, they can also cause injury. LaPrade et al. (1995) observed that 69% of facial lacerations for a National College Athletic Association Division I intercollegiate hockey team occurred on the chin and were caused by a single chin strap. Perhaps the use of a double chin strap might better protect the helmet from riding back during head collisions and prevent injury to the chin.

Environment

Agel et al. (2000b) suggest that hockey equipment is effective in dissipating some of the forces applied with sticks and pucks but is probably less effective when collisions occur with other players, the boards, or the ice surface. Therefore, changing the composition of boards to facilitate energy absorption should be investigated in an attempt to reduce the overall rate of injuries in ice hockey.

Playing surface size has also been shown to affect injury rates. Wennberg (2005) demonstrated that fewer player-to-player contacts occur on larger ice surfaces, where collisions were reduced significantly on both the intermediate (94 ft wide) and the large international (100 ft wide) ice surfaces as compared with the small (85 ft wide) ice surface typical of North America. Similarly, both Watson et al. (1997) and Tegner and Lorentzon (1991) established that injury rates were higher on lower-than-standard ice surfaces but lower than on the standard and smaller-than-standard ice surfaces. Thus, larger ice surface size results in lower rates of injury.

Table 28.10 Percent comparison of mechanism of injury among junior, collegiate, and professional ice hockey players.

Study	Age, yr	Sample, no. of subjects	Sample, no. of teams	Duration, no. of seasons (time frame)	No. of Injuries
Junior					
Stuart & Smith (1995)	17–20	25	1	3 (1990–1993)	142
Stuart et al. (2002)	16–21	282	10	3 (?)	113
Pinto et al. (1999)	16–20	22	1	1 (?)	74
College					
Schick & Meeuwisse (2003)	Mean: W: 20.9 M: 23.5	O: 261 W: 114 M: 147	O: 12 W: 6 M: 6	1 (1998–1999)	O: 227 W: 66 M: 16
Yohann (2001)	18–25	468	1 team/15 seasons	15 (1984–2001)	1,251
Benson et al. (1999)	HFS: 18–29 FFS: 17–29	642	22	1 (1997–1998)	FL: HFS: 204 FFS: 195
Benson et al. (2002)	Median: 22	642	22	1 (1997–1998)	CO: HFS: 41 FFS: 38
Flik et al. (2005)	?	?	8	1 (2001–2002)	113
McKnight et al. (1992)	?	?	7	3 (1987–1990)	280
Pelletier et al. (1993)	19–25	Mean: 19 players/game	?	6 (1979–1985)	188
Professional					
Molsa et al. (1997)	18–37	?	7	1 (1988–1989)	O: 189 FNL: 134 DIV: 55
Pettersson & Lorentzon (1993)	Mean: 25	Mean: 22–25 players/ season	1	4 (1986–1990)	376
Agel et al. (2007a)	?	?	43	4 (2000–2004)	431
Agel et al. (2007b)	?	?	501	16 (1988–2004)	6,639
Groger (2001)	14–19	Mean: 22/team	?	11 (1986–1995)	147
Lorentzon et al. (1988a)	17–29	24–25 play-ers/season	1	3 (1982–1985)	95
Lorentzon et al. (1988b)	19–33	22–25 players/ team	1	1 (1984–1985)	Overall: 19 FL only: 17

Illegal Play (%)	Body Check/ Collision (%)	Stick Contact (%)	Puck Contact (%)	Skate Contact (%)	Fall (%)	Other/Unknown (%)
	51	14	11	3		22
	32.7	36.3	6.2		6.2	18.6
	12.2	16.2		†2.7		31.1
	W: 90.33 M: 74.42	M: 12.79				W: 9.68 M: 12.79
	44.5	11.2	10.6	5.1	4.4	24.2
	HFS: 25.0 FFS: 43.3	HFS: 56.3 FFS: 40	HFS: 6.3 FFS: 3.3	HFS: 7.5 FFS: 0.0	HFS: 3.8 FFS: 10.0	HFS: 1.3 FFS: 3.3
	82.9	4.9	0	2.4	4.9	4.9
	57.6	1.6	6.2	3.5	6.0	24.0
	61.5	5.7	9.6			12.5
18.0	73.4					8.7
	57.8	14.6	7.9		6.7	13
	31.1	26.1	16	2.1	4	20.7
	O: 65.8 CO: 64.9	O: 6.5 CO: 3.5	O: 3.0	CO: 1.8	O: 14.8 CO: 28.1	O: 9.9 CO: 1.8
	O: 70.4 CO: 86.5	O: 6.4	O: 7.0		O: 5.9 CO: 7.1	O: 1.1 CO: 6.4
	77.6	12.2	6.8			3.4
	64.5	11.8	14.5	2.6		6.6
	84.2		5.3	5.3		5.3

(*continued*)

Table 28.10 (*continued*)

Study	Age, yr	Sample, no. of subjects	Sample, no. of teams	Duration, no. of seasons (time frame)	No. of Injuries
Molsa et al. (2000)	?	1976–1979: 17 players/team × 7 1988–1989: 22 players/team × 5 1992–1993: 22 players/team × 3	15	5 (1976–1979; 1988–1989; 1992–1993	O: 641 1976–1979: 367 1988–1989: 144 1992–1993: 130
Tegner & Lorentzon (1991)	?	?	12	1 (1988–1989)	285
LaPrade et al. (1995)	?	?	1	4 (?)	FL: 16
Tegner & Lorentzon (1996)	?	R: 265 P: 480	R: 11 P: 14	R: ? (?) P: 4 (1988–1992)	R: CO—87 P: All—805 CO—52

CO = concussion only; DIV = Finnish Division I Men's League (second highest playing league in Finland); FFS = full face shield; FL =
† Includes contact with both goalposts and players' skates.

Rules

Rules and regulations are an important part of any sport, and can reduce injury incidence when strictly and properly enforced. Between 1989 and 1990, the Ontario Universities Athletic Association (OUAA) hockey league imposed stricter penalties against checking from behind (CFB) (Watson et al. 1996). The new rule gave the referee the discretion to assign either a minor or major penalty, regardless of injury occurrence, for a CFB anywhere on the ice. Watson et al. (1996) observed that the introductory of stricter penalties resulting from CFB created a safer environment in the OUAA and resulted in significant decreases in injury rates for the head, neck, and back.

Further research is needed, however, to determine whether such strategies are effective. It is important for sports' governing bodies to "do their homework" prior to introducing new prevention strategies to make sure the strategies do not result in other adverse health effects (i.e., risk compensation). Also, once specific actions are taken, such as the introduction of a new rule or equipment standard, it is important that sport epidemiologic research continues to assess the effectiveness of the prevention program.

Further Research

The occurrence and nature of injuries is often greatly influenced by variations in resistance to the mechanical energy exchanges that occur in sports (Haddon 1980). Some of the differences in susceptibility to injury are genetic (e.g., somatotype, bone density, reflexes), while others are behavioral (e.g., aggressiveness, rule compliance, physical conditioning). In addition, there are interindividual variations in injury thresholds or rates of mechanical energy exchanges that can be tolerated without injury under given environmental conditions. An interaction between the susceptible individual, injury agent (mechanical energy), and environment, together with the impact conditions, ultimately determine whether an injury will occur (Haddon 1980).

Results provided by sport scientists/epidemiologists are valuable information for sports governing bodies that must continually make rational policy and safety decisions for any given sport. Those responsible for hockey need to know what is actually going on both to make informed decisions and to rebut unsubstantiated claims and

Illegal Play (%)	Body Check/ Collision (%)	Stick Contact (%)	Puck Contact (%)	Skate Contact (%)	Fall (%)	Other/Unknown (%)
	76–79: 41 88–89: 68 92–93: 68	76–79: 29 88–89: 21 92–93: 19	76–79: 18 88–89: 12 92–93: 11	76–79: 4 88–89: 1 92–93: 1	76–79: 10 88–89: 10 92–93: 8	76–79: 14 88–89: 8 92–93: 19
	33.7	25.5	11.2	1.5	4.1	24
	62.5	18.8	18.8			
	82	6	4			8

facial laceration only ; FNL = Finish National League; HFS = half face shield; M = men; O = overall; W = women.

recommendations. Although comparisons of findings reported in the literature are an essential part of the decision-making process, the lack of validity of some studies makes such comparisons difficult (e.g., differing injury definitions, different methods of data collection, different player populations at risk, comparisons of prospective and retrospective data, unknown validity of the recording mechanism). In addition, governing bodies must carefully consider the injury trade-offs associated with rule changes and various types of protective equipment, because every decision has certain advantages and disadvantages. By reducing one risk or danger, other risks may be created (Hagel & Meeuwisse 2004). When the risk of injury in ice hockey is high, governing bodies have a responsibility to manage risks to put them at acceptable levels (Fuller 2007). Lastly, injury-prevention strategies should ideally make ice hockey a safer sport without changing the nature of the sport enjoyed by millions worldwide.

The following steps have been either instituted by hockey associations/leagues or proposed in the literature in an attempt to reduce the predictable, unnecessary risks and control those that are understood to be inherent to the game:

- certified helmet and facial protection use and improvement of equipment standards;
- mandated use of face shield by several ice hockey associations;
- introduction of official rules to reduce injury through illegal play;
- providing reasons for rule changes by sport scientists and the media;
- adding a second official to the current team of one referee and two linesmen. This has been instigated at the professional level of competition, however, the effectiveness has not yet been reported;
- increasing rink dimension standards to make the playing surface less congested (i.e., more open style of play), thereby reducing the amount of hazard;
- increasing awareness of risk factors for potentially catastrophic head and neck injuries to players, coaches, league officials, referees, and parents through the media, informational brochures, and videos;

- strict rule enforcement and harsher penalization of illegal play, such as deliberate hits to the head, checking from behind, slashing, high-sticking, cross-checking, and elbowing;
- eliminating "one-touch" icing rules, which frequently result in players getting "run" into the end boards from behind while racing for the puck;
- enhanced sport-specific preseason strength and conditioning to increase players' resistance to injury;
- the use of custom mouth guards fitted by dentists;
- certification in basic first aid training for all coaches, trainers, and referees;
- mandatory emergency communication systems and access to medical personnel in all rinks;
- enhancement of player respect through strict officiating rules that result in severe consequences to any individual who deliberately attempts to injure another player through an illegal action;
- enhanced coaching techniques, particularly body-checking technique;
- eliminating body checking in the Pee Wee ages of competition and lower, and adult recreational leagues;
- introduction of fair-play concepts (e.g., respect, attitudes, behavior) among players, coaches, parents, spectators, etc.

Future research should thus focus on examining those recommendations that have not yet been studied, and should take into consideration as many of the following design characteristics as possible: (1) natural experimental sport setting; (2) prospective injury reporting; (3) specific target populations; (4) sufficient sample size/power to be able to detect a difference in injury rates if it truly exists; (5) strict definition of injury and markers of injury severity; (6) qualified personnel assessing and reporting injury; (7) validated system of injury surveillance; (8) direct measurement of individual athlete participation (exposure) and potential risk-factor exposure during practices and games, and during preseason period, regular season, and playoffs; (9) more accurate recording of mechanism of injury (e.g., video); and (10) standardized reporting of injury rates so that they are comparable between studies and sports. Finally, a consensus meeting on ice hockey research protocol would likely enhance further development and execution of injury-prevention strategies.

References

ADA Council on Access, Prevention and Interprofessional Relations & ADA Council on Scientific Affairs (2006) Using mouthguards to reduce the incidence and severity of sports-related oral injuries. *Journal of the American Dental Association* **137**, 1712–1720.

Agel, J., Dick, R., Nelson, B., Marshall, S.W., & Dompier, T.P. (2007a) Descriptive epidemiology of collegiate women's ice hockey injuries: National Collegiate Athletic Association Injury Surveillance System, 2000–2001 through 2003–2004. *Journal of Athletic Training* **42**, 249–254.

Agel, J., Dompier, T.P., Dick, R. & Marshall, S.W. (2007b) Descriptive epidemiology of collegiate men's ice hockey injuries: National Collegiate Athletic Association Injury Surveillance System, 1988–1989 through 2003–2004. *Journal of Athletic Training* **42**, 241–248.

Benson, B.W. & Meeuwisse, W.H. (2005) Ice hockey injuries. *Medicine & Sport Science* **49**, 86–119.

Benson, B.W., Mohtadi, N.G., Rose, M.S. & Meeuwisse, W.H. (1999) Head and neck injuries among ice hockey players wearing full face shields vs half face shields. *Journal of the American Medical Association* **282**, 2328–2332.

Benson, B.W., Rose, M.S., & Meeuwisse, W.H. (2002) The impact of face shield use on concussions in ice hockey: a multivariate analysis. *British Journal of Sports Medicine* **36**, 27–32.

Biasca, N., Simmen, H.P., Bartolozzi, A.R., & Trentz, O. (1995) Review of typical ice hockey injuries: survey of the North American NHL and Hockey Canada versus European leagues. *Unfallchirurg* **98**, 283–288.

Biasca, N., Wirth, S. & Tegner, Y. (2005) Head injuries and facial injuries in ice hockey: role of the protective equipment. *European Journal of Trauma* **31**, 369–374.

Bishop, P. & Wells, R. (1989) Cervical spine fractures: mechanisms, neck loads, and methods of prevention. In: Safety in Ice Hockey (Castaldi, C.R. & Hoerner E.F., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 71–83.

Cantu, R.C. (1997) Minor head injuries in sports. *Clinical Journal of Sport Medicine* **7**, 83–84.

Cantu, R.C. & Mueller, F.O. (2008) Fatalities and catastrophic injuries in high school and college sports, 1982–1997. *Physician and Sportsmedicine* **27**, 35–48.

Cohenca, N., Roges, R.A., & Roges, R. (2007) The incidence and severity of dental trauma in intercollegiate athletes. *Journal of the American Dental Association* **138**, 1121–1126.

Cunningham, C. (1995) Hockey injuries. *Emergency* **27**, 34–37.

Ekstrand, J. & Gillquist, J. (1983) The avoidability of soccer injuries. *International Journal of Sports Medicine* **4**, 124–128.

Emery, C.A. & Meeuwisse, W.H. (2001) Risk factors for groin injuries in hockey.

Medicine & Science in Sports & Exercise **33**, 1423–1433.
Emery, C.A., Meeuwisse, W.H., & Powell, J.W. (1999) Groin and abdominal strain injuries in the National Hockey League. *Clinical Journal of Sport Medicine* **9**, 151–156.
Ferrara, M.S. & Schurr, K.T. (1999) Intercollegiate ice hockey injuries: a causal analysis. *Clinical Journal of Sport Medicine* **9**, 30–33.
Finke, R., Gerberich, S.G., Madden, M., Funk, S., Murray, K., Priest, J.D. & Aamoth, G.M. (1988) Shoulder injuries in hockey. *Journal of Orthopaedic and Sports Physical Therapy* **10**, 54–58.
Flik, K., Lyman, S. & Marx, R.G. (2005) American collegiate men's ice hockey: an analysis of injuries. *American Journal of Sports Medicine* **33**, 183–187.
Fuller, C.W. (2007) Managing the risk of injury in sport. *Clinical Journal of Sport Medicine* **17**, 182–187.
Goodman, D., Gaetz, M. & Meichenbaum, D. (2001) Concussions in hockey: there is cause for concern. *Medicine and Science in Sports and Exercise* **33**, 2004–2009.
Greenberg, R.S., Daniels, S.R., Flanders, W.D., Eley, J.W. & Boring, J.R. (2005) *Medical Epidemiology*. McGraw-Hill Companies, New York, NY.
Groger, A. (2001) Ten years of ice hockey-related-injuries in the German Ice Hockey Federation—a ten year prospective study/523 international games. *Sportverletzung Sportschaden* **15**, 82–86.
Haddon, W., Jr. (1980) Advances in the epidemiology of injuries as a basis for public policy. *Public Health Report* **95**, 411–421.
Hagel, B.E. & Meeuwisse, W.H. (2004) Risk compensation: a "side effect" of sport injury prevention? *Clinical Journal of Sport Medicine* **14**, 193–196.
Hawn, K.L., Visser, M.F. & Sexton, P.J. (2002) Enforcement of mouthguard use and athlete compliance in National Collegiate Athletic Association men's collegiate ice hockey competition. *Journal of Athletic Training* **37**, 204–208.
Horns, R.C. (1976) Blinding hockey injuries. *Minnesota Medicine* **59**, 255–258.
Jorgensen, U. & Schmidt-Olsen, S. (1986) The epidemiology of ice hockey injuries. *British Journal of Sports Medicine* **20**, 7–9.
Kelly, K.D., Lissel, H.L., Rowe, B.H., Vincenten, J.A. & Voaklander, D.C. (2001) Sport and recreation-related head injuries treated in the emergency department. *Clinical Journal of Sport Medicine* **11**, 77–81.
Knapik, J.J., Bauman, C.L., Jones, B.H., Harris, J.M., & Vaughan, L. (1991) Preseason strength and flexibility imbalances associated with athletic injuries in female collegiate athletes. *American Journal of Sports Medicine* **19**, 76–81.
LaPrade, R.F., Burnett, Q.M., Zarzour, R. & Moss, R. (1995) The effect of the mandatory use of face masks on facial lacerations and head and neck injuries in ice hockey. a prospective study. *American Journal of Sports Medicine* **23**, 773–775.
Lorentzon, R., Wedren, H. & Pietila, T. (1988a) Incidence, nature, and causes of ice hockey injuries: a three-year prospective study of a Swedish elite ice hockey team. *American Journal of Sports Medicine* **16**, 392–396.
Lorentzon, R., Wedren, H., Pietila, T. & Gustavsson, B. (1988b) Injuries in international ice hockey: a prospective, comparative study of injury incidence and injury types in international and Swedish elite ice hockey. *American Journal of Sports Medicine* **16**, 389–391.
McCrory, P. (2001) Do mouthguards prevent concussion? *British Journal of Sports Medicine* **35**, 81–82.
McKnight, C.M., Ferrara, M.S. & Czerwinska, J.M. (1992) Intercollegiate ice hockey injuries: a three-year analysis. *Journal of Athletic Training* **27**, 338–343.
Miller, M.G., Berry, D.C., Gariepy, G.S., & Tittler, J.G. (2006) Attitudes of high school ice hockey players toward mouthguard usage. *Internet Journal of Allied Health Sciences and Practice* 4, 6p.
Molsa, J., Airaksinen, O., Nasman, O. & Torstila, I. (1997) Ice hockey injuries in Finland: a prospective epidemiologic study. *American Journal of Sports Medicine* **25**, 495–499.
Molsa, J., Kujala, U., Myllynen, P., Torstila, I. & Airaksinen, O. (2003) Injuries to the upper extremity in ice hockey: analysis of a series of 760 injuries. *American Journal of Sports Medicine* **31**, 751–757.
Molsa, J., Kujala, U., Nasman, O., Lehtipuu, T.P. & Airaksinen, O. (2000) Injury profile in ice hockey from the 1970s through the 1990s in Finland. *American Journal of Sports Medicine* **28**, 322–327.
Molsa, J.J., Tegner, Y., Alaranta, H., Myllynen, P., & Kujala, U.M. (1999) Spinal cord injuries in ice hockey in Finland and Sweden from 1980 to 1996. *International Journal of Sports Medicine* **20**, 64–67.
Newsome, P.R., Tran, D.C. & Cooke, M.S. (2001) The role of the mouthguard in the prevention of sports-related dental injuries: a review. *International Journal of Paediatric Dentistry* **11**, 396–404.
Pashby, T. (1985) Eye injuries in Canadian amateur hockey. *Canadian Journal of Ophthalmology* **20**, 2–4.
Pashby, T. (1987) Eye injuries in Canadian amateur hockey still a concern. *Canadian Journal of Ophthalmology* **22**, 293–295.
Pashby, T.H. (1981) Eye injuries in hockey. *International Ophthalmology Clinics* **21**, 59–86.
Pashby, T.J. (1977) Eye injuries in Canadian hockey: phase II. *Canadian Medical Association Journal* **117**, 671–672.
Pashby, T.J. (1979a) Eye injuries in Canadian amateur hockey. *American Journal of Sports Medicine* **7**, 254–257.
Pashby, T.J. (1979b) Eye injuries in Canadian hockey: phase III: older players now most at risk. *Canadian Medical Association Journal* **121**, 643–644.
Pashby, T.J., Pashby, R.C., Chisholm, L.D. & Crawford, J.S. (1975) Eye injuries in Canadian hockey. *Canadian Medical Association Journal* **113**, 663–666.
Pelletier, R.L., Montelpare, W.J. & Stark, R.M. (1993) Intercollegiate ice hockey injuries: a case for uniform definitions and reports. *American Journal of Sports Medicine* **21**, 78–81.
Pettersson, M. & Lorentzon, R. (1993) Ice hockey injuries: a 4-year prospective study of a Swedish elite ice hockey team. *British Journal of Sports Medicine* **27**, 251–254.
Pforringer, W. & Smasal, V. (1987) Aspects of traumatology in ice hockey. *Journal of Sports Sciences* **5**, 327–336.
Pinto, M., Kuhn, J.E., Greenfield, M.L., & Hawkins, R.J. (1999) Prospective analysis of ice hockey injuries at the Junior A level over the course of one season. *Clinical Journal of Sport Medicine* **9**, 70–74.
Sane, J., Ylipaavalniemi, P. & Leppanen, H. (1988) Maxillofacial and dental ice hockey injuries. *Medicine and Science in Sports and Exercise* **20**, 202–207.
Schick, D.M. & Meeuwisse, W.H. (2003) Injury rates and profiles in female ice hockey players. *American Journal of Sports Medicine* **31**, 47–52.
Sim, F.H. & Chao, E.Y. (1978) Injury potential in modern ice hockey. *American Journal of Sports Medicine* **6**, 378–384.

Slovic, P. (1987) Perception of risk. *Science* **236**, 280–285.

Society for International Hockey Research (2001) The origins of ice hockey: report of the sub-committee looking into claim that Windsor, Nova Scotia, is the birthplace of hockey. URL http://www.sihrhockey.org/origins_report.cfm#terms [accessed December 18, 2007]

Stevens, S.T., Lassonde, M., de Beaumont, L. & Keenan, J.P. (2006) The effect of visors on head and facial injury in National Hockey League players. *Journal of Science and Medicine in Sport* **9**, 238–242.

Stuart, M.J. & Smith, A. (1995) Injuries in Junior A ice hockey: a three-year prospective study. *American Journal of Sports Medicine* **23**, 458–461.

Stuart, M.J., Smith, A.M., Malo-Ortiguera, S.A., Fischer, T.L. & Larson, D.R. (2002) A comparison of facial protection and the incidence of head, neck, and facial injuries in Junior A hockey players: a function of individual playing time. *American Journal of Sports Medicine* **30**, 39–44.

Tator, C.H. (1987) Neck injuries in ice hockey: a recent, unsolved problem with many contributing factors. *Clinics in Sports Medicine* **6**, 101–114.

Tator, C.H., Carson, J.D., & Edmonds, V.E. (1997) New spinal injuries in hockey. *Clinical Journal of Sport Medicine* **7**, 17–21.

Tegner, Y. & Lorentzon, R. (1991) Ice hockey injuries: incidence, nature and causes. *British Journal of Sports Medicine* **25**, 87–89.

Tegner, Y. & Lorentzon, R. (1996) Concussion among Swedish elite ice hockey players. *British Journal of Sports Medicine* **30**, 251–255.

Tyler, T.F., Nicholas, S.J., Campbell, R.J., & McHugh, M.P. (2001) The association of hip strength and flexibility with the incidence of adductor muscle strains in professional ice hockey players. *American Journal of Sports Medicine* **29**, 124–128.

Watson, R.C., Nystrom, M.A., & Buckolz, E. (1997) Safety in Canadian junior ice hockey: the association between ice surface size and injuries and aggressive penalties in the Ontario Hockey League. *Clinical Journal of Sport Medicine* **7**, 192–195.

Watson, R.C., Singer, C.D. & Sproule, J.R. (1996) Checking from behind in ice hockey: a study of injury and penalty data in the Ontario University Athletic Association Hockey League. *Clinical Journal of Sport Medicine* **6**, 108–111.

Wennberg, R. & Tator, C. (2003) National Hockey League reported concussions, 1986–87 to 2001–02. *The Canadian Journal of Neurological Sciences* **30**, 206–209.

Wennberg, R. (2005) Effect of ice surface size on collision rates and head impacts at the World Junior Hockey Championships, 2002 to 2004. *Clinical Journal of Sport Medicine* **15**, 67–72.

Willer, B., Kroetsch, B., Darling, S., Hutson, A. & Leddy, J. (2005) Injury rates in house league, select, and representative youth ice hockey. *Medicine and Science in Sports and Exercise* **37**, 1658–1663.

Winters, J.E., Sr. (2001) Commentary: Role of properly fitted mouthguards in prevention of sport-related concussion. *Journal of Athletic Training* **36**, 339–341.

Wisniewski, J.F., Guskiewicz, K., Trope, M. & Sigurdsson, A. (2004) Incidence of cerebral concussions associated with type of mouthguard used in college football. *Dental Traumatology* **20**, 143–149.

Yard, E.E. & Comstock, R.D. (2006) Injuries sustained by pediatric ice hockey, lacrosse, and field hockey athletes presenting to United States emergency departments, 1990–2003. *Journal of Athletic Training* **41**, 441–449.

Yohann, A. (2001) *Ice Hockey Injuries: A 17 Year Retrospective Analysis.* Faculty of Education, McGill University, Montreal

Chapter 29

Snowboarding

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Introduction

The first snowboards were designed in the 1960s, and snowboarding became a demonstration sport during the 1994 Olympics in Lillehammer, Norway. It was officially declared an Olympic sport for the 1998 Games in Nagano, Japan (Olympic Movement 2007).

The purpose of this chapter is to systematically identify and synthesize the literature on snowboarding injury rates, patterns, risk factors, and prevention strategies. In total, 94 studies were included. The results were stratified according to injury definition (e.g., self-reported, ski patrol–reported, medical clinic and emergency department [ED] reports).

Who Is Affected by Injury?

Thirty-four studies reported an overall injury rate (Table 29.1). Five studies did not include a precise injury definition (Mclennan & Mclennan 1990; Biasca et al. 1995; Oberthaler et al. 1995; Schrank et al. 1999; Zacharapoulos et al. 2004). Injury rates ranged from 0.8 (Schrank et al. 1999) to 8.0 (Biasca et al. 1995) per 1,000 snowboard days.

Self-Reported Injuries

In a survey of high-school students, Emery et al. (2006) reported a rate of 240 injuries per 1,000 snowboard participants per year (men, 220; women, 260), resulting in restriction of normal daily activities or requiring medical attention in the past year. Torjussen and Bahr (2005) reported rates of injury (at least 1 day missed from activity) between 3.4 (retrospective study) and 4.0 per 1,000 runs (prospective study).

Ski Patrol Reports

Overall ski patrol–reported injury rates ranged from 2.1 (Lipskie et al. 2001) to 7.0 (Shealy & Ettlinger 2004) per 1,000 outings.

Medical Clinics and Emergency Department Reports

Injury rates ranged between 1.5 and approximately 6.0 per 1,000 snowboarder-days, estimated as a proportion of all snowboarder lift tickets. Rates were higher in closed populations: 10.6 per 1,000 days in a cohort of children (Machold et al. 2000) to 41.5 per 1,000 snowboarder-days among beginner snowboarders (O'Neill & McGlone 1999). In elite

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Table 29.1 Overall injury rates.

Study	Study Design	Overall Injury Rate (per 1,000 days)	Overall Injury Rate (per 1,000 snowboarders)	Overall Injury Rate (Other)
Self-Reported Injuries				
Emery et al. (2006), Canada	Cross-sectional survey[a] (n = 142)		240 Men, 220; women, 260	
Michaud et al. (2001), Switzerland	Cross-sectional survey[a] (n = 1,154)			1.5 (1.4–1.6)[h]
Torjussen & Bahr (2005), National Touring Events	Case series with exposure estimation[b] (n = 32) (prospective)			4.0[i]
Torjussen & Bahr (2005), Norway	Case series with exposure estimation[b] (n = 84) (retrospective)			3.4[i]
Torjussen & Bahr (2006), Switzerland	Case series with exposure estimation[c] (n = 62)			7[j] 1.3[k]
Ski Patrol–Reported Injuries				
Ekeland et al. (2004), Norway	Case–control[a] (n = 2,762)	2.3		
Lipskie et al. (2001), Canada	Case series with exposure estimation[a] (n = 2,501)	2.1 7.3–9.6 (age- and sex-adjusted)		
Macnab & Cadman (1996), Canada	Case series with exposure estimation[a] (n = 156)	4.3		
Pogorzelski et al. (2003), Australia	Case series with exposure estimation[a] (n = 1,770)	2.9		
Shealy & Sundman (1989), United States	Case series with exposure estimation[a] (n = 51)	4.2		
Shealy et al. (1997), United States	Case series with exposure estimation[a] (n = 3,696)	6.0		
Shealy & Ettlinger (2004), United States	Case series with exposure estimation[a] (n = 9,561)	7.0		
Injuries Presenting to a Medical Clinic, Emergency Department, or Hospital				
Bladin et al. (1993), Australia	Case series with exposure estimation[a] (n = 276)	4.2		
Crim (2003), United States	Case series with exposure estimation[d] (Olympic athletes)			28[l]
Dohjima et al. (2001), Japan	Case series with exposure estimation[a] (n = 1,776)	2.0		

Federiuk et al. (1997), United States	Case series with exposure estimation[a] (n = 462; 1995–1996) (n = 622; 1996–1997)	1995–1996: 6.8 1996–1997: 5.6		
Huber et al. (1995), United States	Case series[a] (n = 120)	4.2% (units NR)		
Llorens et al. (2005), Spain	Case series with exposure estimation[a] (n = NR)	5.3		
Machold et al. (2000), Austria	Prospective cohort[a] (n = 2,579)	10.6 Men, 14.2; women, 16.6		
Made & Elmqvist (2004), Sweden	Case series with exposure estimation[a] (n = 568)	3		
Matsumoto et al. (2004), Japan	Case series with exposure estimation[a] (n = 740)	2.1		
O'Neill et al. (1999), United States	Prospective cohort[a] (n = 6,585)		First time, 41.5 Emergent, 17.5 Nonemergent, 24.0	
Ronning et al. (2000), Norway	Case series with exposure estimation[a] (n = 1,411)			0.14[m]
Sasaki et al. (1999a), Japan	Case series with exposure estimation[a] (n = 1,445)	3.5		
Shealy & Ettlinger (1996); Shealy (1993), United States	Case series with exposure estimation[a] (n = NR)	Men, 2.8; women, 4.1 Beginners: men, 11.2; women, 11.7 Intermediate: men, 2.2; women, 2.0 Advanced: men, 0.8; women, 0.6		
Wakahara et al. (2006), Japan	Case series with exposure estimation[a] (n = 15,320)	1.5		
Xiang et al. (2005), United States	Case series with exposure estimation[a] (n = 62,005)		Age 10–13 yr, 15.9 Age 14–17yr, 15.0 Age 18–24 yr, 13.5	Age 10–13 yr, 8.8[n] Age 14–17 yr, 10.1[n] Age 18–24 yr, 5.4[n]
Yamakawa et al. (2001), Japan	Case series with exposure estimation (n = 238)	1.8		

(*continued*)

Table 29.1 (*continued*)

Study	Study Design	Overall Injury Rate (per 1,000 days)	Overall Injury Rate (per 1,000 snowboarders)	Overall Injury Rate (Other)
Injuries Admitted to the Hospital				
Sacco et al. (1998), United States	Case series with exposure estimation[a] (n = 40)	0.9		
Injuries in a Trauma Registry or Presented to a Trauma Center				
Prall et al. (1995), United States	Case series with exposure estimation[a] (n = 37)	Severe injury, 0.03		
Injuries Resulting in Death				
Shealy et al. (2000), United States	Case series with exposure estimation[e] (n = 28 deaths)			Fatality, 0.5[o]
Injury Setting Not Reported				
Biasca et al. (1995), Switzerland	Case series with exposure estimation[a] (n = NR)	1.7–8.0		
Mclennan & Mclennan (1990), United States	Case series with exposure estimation[a] (n = 300)			1.0–1.7[p]
Schrank et al. (1999), Germany	Case series with exposure estimation[f] (n = 95)			0.8[p]
Zacharapoulos et al. (2004), Greece	Case–control (n = NR)	6.8		

NR = not reported; SNBD = snowboard.
[a] All injuries.
[b] Any acute injury causing cessation of participating in competition or training for ≥1 day.
[c] All acute (miss ≥1 day of competition/training) and overuse injuries.
[d] Injuries with a positive imaging study.
[e] Recreational snowboarders who suffered an immediate traumatic death within bounds of ski area.
[f] Not reported.
[g] Relative risk of SNBD injury versus mean rate of *sport* injury for other sports.
[h] Per 1,000 runs.
[i] Per 1,000 days in competition.
[j] Per 1,000 runs in competition.
[k] Per 1,000 races.
[l] Equipment-specific Distance Correlated Injury Index/1,000 km.
[m] Per 1,000 population.
[n] Per 1 million days.
[o] Per 1,000 hours of exposure.

competition, Crim (2003) reported a rate of 28 per 1,000 races.

Hospital Admissions and Trauma Registry Reports

The injury rates ranged from 0.03 (Prall et al. 1995) to 0.9 (Sacco et al. 1998) per 1,000 snowboarder-days.

Summary

Depending on the injury definition, rates ranged from 0.03 per 1,000 snowboarder-days (Prall et al. 1995) to 41.5 (O'Neill 1999) per 1,000 snowboarders.

Where Does Injury Occur?

Anatomical Location

Fifty-four studies reported the proportion of injuries by anatomical location (Table 29.2), and 20 studies provided injury rates by anatomical location.

Self-Reported Injuries

Machold et al. (2002) reported a rate of severe wrist injury of 16.6 per 1,000 snowboarders. In the survey of high school students by Emery et al. (2006), head injuries represented 28% of all injuries, followed by lower-extremity (LE) injuries (28%) and wrist injuries (18%). Torjussen and Bahr (2006) examined injuries among World Cup athletes resulting in at least 1 day of missed competition or training and overuse injuries; the most common acute injury locations were knee, shoulder, back, and wrist.

Ski Patrol Reports

Hagel et al. (2004) reported a head-and-neck injury rate of 0.37 per 1,000 snowboarder-days, or 2.48 per 1,000 snowboarders per year. The injury rates per 1,000 snowboarder-days and per 1,000 snowboarders, respectively, for the upper extremity (UE) were 0.97 and 6.6; for the LE, 0.36 and 2.48; for the trunk, 0.16 and 1.06; and for the head and neck, 0.37 and 2.48.

Based on ski patrol reports, head injuries represent between 9% and 20% (Shealy and Sundman 1989; Lamont 1995; Pogorzelski et al. 2003) of all injuries, while neck injuries accounted for between 1% (Davidson & Laliotis 1996) and 4% (Made et al. 2003). UE injuries were frequently reported to the ski patrol, accounting for 16% (Goulet et al. 2007) to over 60% (Ekeland & Rodven 2000) of injuries. The wrist was the most common UE injury location, ranging from 19% (Davidson & Laliotis 1996) to 31% (Hagel et al. 1999). LE injuries represented between 13% (Goulet et al. 2007) and 40% (Davidson & Laliotis 1996) of all ski patrol–reported injuries in snowboarders, with knee and ankle injuries generally the most common within this body region (Shealy & Sundman 1989; Calle & Evans 1995; Sutherland et al. 1996; Davidson & Laliotis 1996; Ekeland & Rodven 2000; Bridges et al. 2003).

Medical Clinics and Emergency Department Reports

Head-injury rates ranged between 0.002 (Siu et al. 2004) and 0.5 (Sasaki et al. 1999a) per 1,000 snowboarder-days. Brain-injury rates have been reported at 0.05 per 1,000 snowboarder-days (Hagel et al. 2003). Bladin et al. (1993) reported a rate of head, neck, and face injuries of 0.45 per 1,000 snowboarder-days. Spine-injury rates ranged from 0.005 (Siu et al. 2004) to 0.06 Yamakawa et al. (2001) per 1,000 snowboarder-days. UE injury rates ranged between 0.7 (Matsumoto et al. 2002) to 1.8 (Sasaki et al. 1999a) per 1,000 snowboarder-days. Wrist-injury rates were between 0.45 per 1,000 snowboarder days (Sasaki et al. 1999b) and 17 per 1,000 first-time snowboarders (O'Neill 2003). Sasaki et al. (1999a) reported LE and trunk injury rates of 0.96 and 0.29 per 1,000 participants, respectively.

Proportionally, head injuries accounted for between 2% and 23% (Janes & Abbot 1999; Made et al. 1995) of medical clinic or ED-evaluated injuries, whereas neck injuries accounted for less than 5%. UE injuries accounted for 29% to 79%, with wrist injuries being the most common. LE injuries were reported by 7% of the children in the series by Drkulec and Letts (2001), but 57% in the Bladin et al.'s (1993) study of all ages. When reported, the knee and ankle were the most common LE injury sites (Table 29.2).

Table 29.2 Proportion of injuries by anatomical location.

Study	Head	Neck	Upper extremity	Lower extremity	Spine/back	Other
Self-Reported Injuries						
Emery et al. (2006) (n = 142)[a]	Head, 28% Face, 1%	4%	Shoulder, 6% Wrist, 18%	Hip, 2% Upper leg, 3% Knee, 8% Lower leg, 6% Ankle, 4% Foot, 1%	Back, 5%	
Torjussen & Bahr (2005) (n = 32 injuries)[b] Prospective	13%	3%	Shoulder, 16% Arm/wrist, 9%	Hip, 6% Knee, 16% Ankle, 3%	22%	Chest/ribs, 13%
Torjussen & Bahr (2005) (n = 84 injuries)[b] Retrospective	13%		Shoulder, 10% Lower arm/wrist, 12%	Hip, 4% Thigh, 1% Knee, 15% Lower leg, 2% Ankle, 2% Foot/toes, 2%	13%	Chest, 12%
Ski Patrol–Reported Injuries						
Bridges et al. (2003) (n = 434 injuries)[a]	14%	4%	Clavicle, 6% Shoulder, 10% Arm, 2% Forearm/elbow, 6% Wrist, 23% Hand/thumb, 3%	Leg, 1% Knee, 7% Ankle/foot, 6%	Thorax/spine, 10%	Abdomen, 2% Pelvis/thigh, 4%
Calle & Evans (1995) (n = 487)[a]	10%	2%	UE, 38% Shoulder, 8% Wrist, 20%	LE, 34% Knee, 15% Ankle, 13%		
Davidson & Laliotis (1996) (n = 931)[a]	Head/ face, 10%	Neck/ throat, 1%	Arm, 5% Shoulder, 8% Elbow, 2% Wrist, 19% Hand, 4%	Hip/pelvis, 1% Lower leg, 5% Thigh, 0.1% Knee, 17% Ankle, 16% Foot, 0.4%	3%	Chest/ abdomen, 0.6% Clavicle, 2%
Ekeland & Rodven (2000) (n = 1,224)[a]	16%	2%	Arm, 12% Shoulder, 12% Wrist, 29% Hand, 8%	Thigh, 1% Knee, 6% Lower leg, 2% Ankle, 4%	Back, 6%	Thorax/ abdomen, 3%
Gajdzinska et al. (2006) (n = 62 injuries)[a]	14%		Forearm, 21% Wrist, 25%	Knee, 16%		NR, 24%

Goulet et al. (2007) (n = 6,084)[d]	Head/ neck, 48%		UE, 16%	LE, 13%		Trunk, 23%
Hagel et al. (1999) (n = 557)[a]	20%		Wrist, 31%			
Lamont (1995) (n = 379)[a]	9%		Lower end radius, 31% Wrist/hand, 16% MCP, 6%	Lower leg, 43% Ankle, 43%		Trunk, 8%
Pogorzelski et al. (2003) (n = 1,770 injuries)[a]	9%		UE, 49%			
Shealy & Sundman (1989) (n = 59)[a]	9%		Shoulder, 9% Wrist/hand/finger, 17%	Knee, 15% Ankle/foot, 36%		
Sutherland et al. (1996) (n = 57)[a]	Head/ neck/ face, 23%		Upper arm/shoulder, 28% Hand/forearm, 56%	Lower leg, 4% Knee, 26% Ankle, 16%		Trunk/back/ thigh, 18%
Injuries Presenting to a Medical Clinic, Emergency Department, or Hospital						
Abu-Laban (1991) (n = 132 injuries)[a]	Head/ face, 2%	3%	Clavicle/ shoulder, 10% Upper arm, 2% Forearm, 1% Elbow, 2% Wrist/hand, 17%	Hip, 2% Thigh, 1% Lower leg, 1% Knee, 16% Ankle, 28% Foot, 2%		Central body, 12% Spleen, 1%
Bladin et al. (1993) (n = 276 injuries)[a]	Head/ neck/ face, 11%		Upper limb, 30% Shoulder, 8% Arm/elbow, 5% Wrist/hand, 16%	Lower limb, 57% Knee, 23% Lower leg, 6% Ankle/foot, 23%	Chest/back/ thigh, 6%	
Calle & Evans (1995) (n = 565)[a]	5%	1%	UE, 47% Shoulder, 11%	LE, 31.8% Knee, 12% Ankle, 12.8% Lower leg, 5.5% Foot, 1.2		
Chow et al. (1996) (n = 390 injuries)[a]	Head, 14% Face, 4%		UE, 58%	LE, 16%	7%	Abdomen, 1% Thorax, 1%
Corra et al. (2004) (n = 331 injuries)[a]	18%		UE, 44%	LE, 17%	17%	Abdomen/pelvis, 2% Chest, 2%
Dohjima et al. (2001) (n = 1,776)[a]	8%		UE, 55%	LE, 17%		
Drkulec & Letts (2001) (n = 118 injuries)[a]	8%		UE, 79%	LE, 7%		Abdomen, 5%

(*continued*)

Table 29.2 (*continued*)

Study	Head	Neck	Upper extremity	Lower extremity	Spine/back	Other
Ganong et al. (1992) (n = 415)[a]	4%		UE, 45%	LE, 44%	Spine/torso, 8%	
Idzikowski et al. (2000) (n = 7,430)[a]			Shoulder/clavicle, 16% Humerus, 0.6% Elbow, 4% Wrist, 22% Forearm, 3% Hand, 4%			
Janes & Fincken (1993) (n = 937 injuries)[a]			UE, 42%	LE, 45% Knee, 9%		
Janes & Fincken (1995) (n = 2,461 injuries)[a]			UE, 38% Wrist, 21% Thumb, 2%	LE, 35% Knee, 15% Ankle, 12%		
Janes & Abbot (1999) (n = 4,390 injuries)[a]	2%		UE, 44% Wrist, 20%	LE, 38% Tibia, 1% Knee, 15% Ankle, 11%	5%	
Made et al. (1995) (n = 43)[a]	23%		UE, 51% Wrist/lower arm, 33%	LE, 14% Knee, 7%		
Made & Elmqvist (2004) (n = 568)[a]	Head/ neck, 15%		UE, 54.4% Shoulder/upper arm/ elbow, 16% Lower arm/wrist, 35% Hand/thumb/finger, 4%	LE, 19% Hip/thigh, 4% Knee, 10% Lower leg, 1% Ankle/foot, 5%	Spine, 8%	Chest/abdomen, 3.7%
Matsumoto et al. (2002) (n = 7,051 injuries)[a]	Head/ neck/ face, 23%		UE, 40%	LE, 14%		Trunk, 23%
Matsumoto et al. (2004) (n = 5,110 injuries)			Wrist, 20%			
Moore (2000) (n = 7,051)[a]			UE, 49%	Ankle, 12%		
Nakaguchi et al. (1999) (n = 143)[e]	Major head, 6%					
O'Neill & McGlone (1999) (n = 273)[a]			UE, 53%	LE, 24%		Trunk, 8%
Pino & Colville (1989) (n = 110 injuries)[a]	4%	3%	Shoulder, 12% Upper arm, 1% Elbow, 3% Wrist, 7% Hand, 6%	Leg, 9% Knee, 12% Ankle, 26% Foot, 3%	Back, 6%	Chest, 6% Buttocks, 3%

Sasaki et al. (1999a) (n = 1,450 injuries)[a]	Head/ neck, 13%	UE, 51% Shoulder, 17% Arm, 2% Elbow, 8% Forearm, 1% Wrist, 19% Hand, 5%	LE, 27% Hip/thigh, 4% Knee, 8% Leg, 4% Ankle/foot, 11%		Trunk, 8%
Shealy & Ettlinger (1996); Shealy (1993) (n = NR)[a]	Face/ head: men, 13%; women, 4%	Wrist: men, 20%; women, 32%	Lower leg: men, 4%; women, 4% Knee: men, 13%; women, 32% Ankle: men, 25%; women, 13%		
Siu et al. (2004) (n = 35)[f]	26%			74%	
Ueland & Kopjar (1998) (n = 506)[a]	Head/ face, 5%	Shoulder/upper arm, 7% Lower arm/wrist/hand, 38%	Knee/lower leg, 14% Ankle/foot, 11%		Torso, 11%
Warme et al. (1995) (n = 47)[a]		Thumb, 2%	Knee, 17% Ankle, 21%		
Yamagami et al. (2004) (n = 3,102)[a]	19%	Shoulder, 12% Upper arm, 1% Elbow, 8% Forearm, 1% Wrist, 13% Hand, 4%	Hip, 0.5% Thigh, 1% Lower leg, 5% Knee, 6% Ankle, 6% Foot, 2%	8%	Pelvis, 4% Chest/abdominal, 8%
Yamakawa et al. (2001) (n = 238)				100%	
Injuries Admitted to the Hospital					
Boldrino & Furian (1999) (n = 102)[a]	12%	UE, 46% Shoulder, 6% Forearm, 14% Wrist, 22%	LE, 46% Knee, 16%	Spinal column, 5%	Chest, 3% Abdomen/pelvis, 5%
Sacco et al. (1998) (n = 40)[a]		UE, 23%	LE, 38%		Renal, 3% Spleen, 13% CNS, 15% Thorax, 8%
Shorter et al. (1999) (n = 27)[a]	44%			15%	Abdomen, 19% Head, 4%

(*continued*)

Table 29.2 (*continued*)

Study	Head	Neck	Upper extremity	Lower extremity	Spine/back	Other
Skokan et al. (2003) (n = 26)[a]	42%		UE, 8%	LE, 15%		Abdomen, 23% Chest, 4%
Injuries in a Trauma Registry or Presented to a Trauma Center						
Levy et al. (2002) (n = 182 injuries)[h]	34%					
Prall et al. (1995) (n = 37)[a]				Femur, 5% Knee, 0% Tibia/fibula 16%	Spine, 5%	CNS, 54% Abdomen, 32% Skeleton, 3%
Injury Setting Not Reported						
Machold et al. (1999) (n = NR)[a]			Wrist, 36%			
Mclennan & Mclennan (1990) (n = 300 injuries)	8%		UE, 62%	LE, 30%		
Oberthaler et al. (1995) (n = 437 injuries)[a]			UE, 51% Wrist, 27%	LE, 34% Knee, 16%		Head/spine/ chest, 15%
Schrank et al. (1999) (n = 75 injuries)[i]			Shoulder, 36% Metacarpals/fingers, 37%	Knee, 33% Ankle, 28%		
Injuries Reported for Insurance Coverage						
Pigozzi et al. (1997) (n = 106)[a]	2%		UE, 45% Shoulder, 16% Elbow, 3% Wrist, 5% Hand, 11%	LE, 39% Thigh, 3% Knee, 17% Ankle, 14%	8%	Abdomen, 7%
Injury Setting Not Reported						
Schröcksnadel et al. (1995) (n = 1,400)[a]			Shoulder, 12% Arm, 42%	Leg, 37% Knee, 22%		

CNS = central nervous system; LE = lower extremity; MCP = metacarpophalangeal; NR = not reported; UE = upper extremity.

[a] All injuries.

[b] Any acute injury causing cessation of participating in competition or training for ⩾1 day.

[c] All acute (missing ⩾1 day of competition/training) and overuse injuries.

[d] Severe injury (Lipskie's classification of severity and/or evacuated by ambulance).

[e] Head injuries.

[f] Head or spine injuries.

[g] Patients with traumatic brain injury entered in a trauma registry.

[h] Not reported.

Hospital Admissions and Trauma Registry Reports

Hentschel et al. (2001) reported a head injury rate of 0.004 per 1,000 snowboarders, while Levy et al. (2002) found a head injury rate of 3.6 per 1,000 snowboarder-days. Head injuries represented between 12% and 44% of all hospital admissions for snowboarding. Central nervous system injuries accounted for between 15% and 54% of these injuries. UE injuries ranged from 8% to 46%, and LE injuries estimated between 15% and 46%.

Environmental Location

Self-Reported Injuries

Torjussen and Bahr (2005) reported that "Big Jump" competitions had the highest injury rate (6.6 [retrospective study] & 14.2 [prospective study] per 1,000 runs) of all snowboarding events. The prospective portion of their study showed that Giant Slalom had the lowest injury rate (1.9 per 1,000 runs); the retrospective portion found half-pipe competitions to have the lowest rate (2.1 per 1,000 runs). Injury rates for boardercross were similar for the prospective (6.1 per 1,000 runs) and retrospective studies (5.8 per 1,000 runs). Torjussen and Bahr (2006) noted injury rates of 1.3 per 1,000 runs in competition, with the highest rate of injury resulting from "Big Air" events among World Cup athletes.

Summary

The highest anatomical location-specific rates for ski patrol or medical clinic/ED-reported injuries were to the UE, especially among beginners. Recreational snowboarders tended to injure their UE, particularly the wrist, while elite level athletes sustained more knee and back injuries. As level of care increases, head and neck injuries with central nervous system involvement represented a greater proportion of injuries.

When Does Injury Occur?

Injury Onset

Torjussen and Bahr (2006) found a greater proportion of acute UE injuries (37%) versus overuse (11%), but overuse injuries were more prevalent in the LE (69% vs. 35%) and back (18% vs. 13%) than acute injuries.

Chronometry

No studies were identified that assessed the chronometry of injury.

What Is the Outcome?

Injury Type

Three studies reported injury rate by type among snowboarders presenting to a medical clinic or ED. Bladin et al. (1993) found sprains to be the most common injury (2.25 per 1,000 snowboarder days), followed by fractures (1.0 per 1,000 snowboarder-days), as did Ronning et al. (2001) (specifically, wrist sprain rate [6.36 per 1,000 snowboarder-days] and wrist fracture rate [0.99 per 1,000 snowboarder-days]). Wakahara et al. (2006) reported a vertebral fracture rate of 0.05 per 1,000 snowboarder-days.

Table 29.3 details the percent distribution of injuries by type. The most common ski patrol–reported injuries were suspected fractures (14–44%) and sprains/strains (13–64%). For injuries reported to medical clinics or EDs, fractures were the most frequent (11–70%), followed by sprains/strains (9–53%). For insurance-reported injuries, the most common types were contusions (31%) and fractures (30%). Fractures represented 16% to >50% of injuries requiring hospitalization.

Time Loss

No study reported injury-related time loss apart from mean length of hospital stay (see "Clinical Outcome" section, below).

Clinical Outcome

Nineteen studies described the clinical outcome by length of hospital stay or injury severity scales (Table 29.4). The Abbreviated Injury Scale (AIS) is a 6-point injury scale, with 1 indicating a minor injury and 6 a nonsurvivable event (Committee on Injury Scaling 1980). The Injury Severity Score (ISS) is a 75-point scoring system based on anatomical location and the squared AIS value of the top three injuries; a higher ISS is more serious (Baker et al.

Table 29.3 Proportion of specific injury types.

Study	Concussion	Fracture	Dislocation	Sprain	Contusion	Laceration	Other
Ski Patrol–Reported Injuries							
Bridges et al. (2003) (n = 434 injuries)[a]	15%						
Davidson & Laliotis (1996) (n = 931)[a]	3%	27%	5%				
Ekeland & Rodven (2000) (n = 1,224)[a]		33%	4%	24%	33%	6%	
Gajdzinska et al. (2006) (n = 62)[a]		39%	23%	13%	16%	6%	Strain, 2 %
Hagel et al. (2005a) (n = 1,108 injuries)[b]		44%	10%	31%	6%		Other, 6%
Pogorzelski et al. (2003) (n = 1,770 injuries)[c]	5%						
Shealy & Sundman (1989) (n = 59)[a]		14%	5%	Sprain/strain, 64%	12%	2%	4%
Sutherland et al. (1996) (n = 57)[a]	7%	18%	13%	33%	12%	9%	Possible fractures, 13%
Injuries Presenting to a Medical Clinic, Emergency Department, or Hospital							
Abu-Laban (1991) (n = 132)[a]		26%	2%	Sprain/strain, 52%	19%		
Bladin et al. (1993) (n = 276 injuries)[a]		24%	4%	53%	12%	4%	3%
Calle & Evans (2005) (n = 565)[a]	2%	37%	4%	31%	18%	5%	
Chow et al. (1996) (n = 390 injuries)[a]	8%	43%	13%	13%	13%	2%	Other, 2% Strain, 2%
Corra et al. (2004) (n = 331 injuries)[a]							Open skin wound, 12%
Dohjima et al. (2001) (n = 1776)[a]		39%	17%	9%	15%	21%	
Drkulec & Letts (2001) (n = 118) injuries[a]	8%	70%	4%	Sprain/strain, 11%			Other, 7%

Ferrera et al. (1999) (n = 71)[a]		42%	4%	13%	25%		13%
Fukuda et al. (2001) (n = 634 injuries)[d]							Neurologic findings, 42% Traumatic amnesia, 33% Transient LOC, 6% Disorientation, 2% Coma, 1%
Ganong et al. (1992) (n = 415)[a]		45%					
Huber et al. (1995) (n = 120)[a]		38%					
Janes & Fincken (1993) (n = 937 injuries)[a]	2%	42%	3%	36%	10%	3%	
Janes & Fincken (1995) (n = 2,461 injuries)[a]		41%		Sprain/strain, 20%	10%		
Made & Elmqvist (2004) (n = 568)[a]		34%		28%	27%	4%	5%
Matsumoto et al. (2002) (n = 7,051 injuries)[a]		UE, 27%	UE, 12%				
Pino & Colville (1989) (n = 110 injuries)[a]		25%		31%	12%	4%	Other, 28% Chronic inflammation, 1%
Sasaki et al. (1999a) (n = 1450 injuries)[a]		31%	10%	19%	21%	13%	Ligament rupture, 4% Other, 3%
Shealy & Ettlinger (1996); Shealy (1993) (n = NR)[a]		Men, 30%; women, 31%	Men, 5%; women, 1%	Sprain/strain: men, 50%; women, 57%		Men, 6%; women, 5%	
Ueland & Kopjar (1998) (n = 506)[a]	1%	38%	1%	31%	14%	2%	
Warme et al. (1995) (n = 47)[a]		11%		13%			Soft tissue, 17%
Xiang et al. (2005) (n = 62,005 injuries)[a]		36%	5%			5%	Soft tissue, 41% TBI, 8%
Yamagami et al. (2004) (n = 3102)[a]		32%	6%	20%	25%	21%	
Yamakawa et al. (2001) (n = 238)[e]		100%					

(*continued*)

Table 29.3 (*continued*)

Study	Concussion	Fracture	Dislocation	Sprain	Contusion	Laceration	Other
Injuries Reported for Insurance Coverage							
Pigozzi et al. (1997) (n = 106)[a]		30%	11%	24%	31%		
Injury Requiring Hospitalization							
Boldrino & Furian (1999) (n = 102)[a]		58%		14%	17%		
Shorter et al. (1999) (n = 27)[a]		78%					
Skokan et al. (2003) (n = 26)[a]	24%	16%				8%	
Tarazi et al. (1999) (n = 27 injuries)[e]		96%		4%			
Injuries in a Trauma Registry or Presented to a Trauma Center							
Hentschel et al. (2001) (n = 14 injuries)[d]	21%	64%					
Injury Setting Not Reported							
Biasca et al. (1995) (n = NR)[a]		28%		46% sprains/strains	14%		
Gajdzinska et al. (2006) (n = 62)[c]	11%	24%	18%			38%	Other, 9%
Mclennan & Mclennan (1990) (n = 300 injuries)[a]	8%						
Oberthaler et al. (1995) (n = 437 injuries)[a]		31%		38%	21%		

LOC = loss of consciousness; TBI = Traumatic brain injury; UE = upper extremity.
[a] All injuries.
[b] Wrist injuries.
[c] Not reported.
[d] Head injuries.
[e] Spine injuries.

Table 29.4 Clinical outcomes.

Study	Severity Score	Any Medical Attention	Admitted	Death
Self-Reported Injuries				
Torjussen & Bahr (2005) (n = 32)[a] Prospective	AIS = 1: 47% AIS = 2: 47% AIS = 3: 6%			
Torjussen & Bahr (2005) (n = 84)[a] Retrospective	AIS = 1: 38% AIS = 2: 60% AIS = 3: 2%			
Torjussen & Bahr (2006) (n = 135)[b]	AIS = 1: 38% AIS = 2: 61% AIS = 3: 1%			
Ski Patrol–Reported Injuries				
Bergstrøm et al. (1999) (n = 11 injuries)[c]	Mean ISS: 3.2			
Injuries Presenting to a Medical Clinic, Emergency Department, or Hospital				
Abu-Laban (1991) (n = 132)[c]				1%
Calle & Evans (1995) (n = 565)[c]				1%
Corra et al. (2004) (n = 293)[c]	ISS <4: 56% ISS 4–24: 43% ISS ⩾25: 1%			
Ferrera et al. (1999) (n = 71)[c]			34%	
Fukuda et al. (2001) (n = 634 injuries)[d]				0.6%
Geddes & Irish (2005) (n = 43)[f]		Splenectomy: 28%	Mean (±SD) LOS: 5.1±2.1 days	
Machold et al. (2000) (n = 152 injuries)[c]	AIS = 1: 64% AIS >1: 36% Rate (SNBD half-days) AIS = 1: 4.8/1,000 AIS = >1: 2.7/1,000	70% Surgery: 3%	12%	
Nakaguchi et al. (1999) (n = 143)[d]		Surgery (head): 2%		0
Xiang et al. (2005) (n = 62,005 injuries)[a]			4%	

(*continued*)

Table 29.4 *(continued)*

Study	Severity Score	Any Medical Attention	Admitted	Death
Injuries Admitted to the Hospital				
Shorter et al. (1999) (n = 27)[c]	ISS: 10.2 (4–34)[e] PTS: 10.5 (7–12)[e]		Surgery: 12 LOS: 3.8 days (1–15)[e]	
Skokan et al. (2003) (n = 26)[c]	ISS >15: 42%		Pediatric ICU: 42% LOS >3 days: 73%	
Tarazi et al. (1999) (n = 22)[g]			Mean LOS (±SD): 5.7±3 days	
Injuries in a Trauma Registry or Presented to a Trauma Center				
Gabl et al. (1991) (n = 59)[c]				3%
Hentschel et al. (2001) (n = 14)[d]	GCS <8: 29% GCS 8–13: 36% GCS 14–15: 36%	Craniotomy: 29%	Mean LOS ICU: 11.8 days Mean LOS: 20.4 days	7%
Levy et al. (2002) (n = 61)[d]	ISS: 10.5 GCS 3–8: 10%	Craniotomy: 3.3% Disposition: Home, 90.2% Rehabilitation, 6.6% Transfer facility, 3.2%	LOS: 3.7 days	0
Prall et al. (1995) (n = 37)[c]	ISS: 8 (1–25)[e] Revised trauma score: 7.8 (6.9–7.8)[e] GCS: 15 (12–15)		Median LOS: 3 days Median LOS ICU: 1 day	
Sacco et al. (1998) (n = 40)[c]	ISS: 11	Surgery: 68%	Mean LOS: 2.9 days	Death rate: 0.23/1,000,000[i]
Shealy et al. (2000) (n = 28)[h]				Death rate: 0.455/1,000,000[j]
Injury Setting Not Reported				
Oberthaler et al. (1995) (n = 437 injuries)[c]		Single office visit: 41% Outpatient treatment: 59% Mean outpatient treatment: 27 days	8% Mean LOS: 4.4 days	

AIS = Abbreviated Injury Scale; GCS = Glasgow Coma Scale; ISS = Injury Severity Score; ICU = intensive care unit; LOS = length of stay; PTS: Pediatric Trauma Score; SNBD = snowboard.

[a] Any acute injury causing cessation of participating in competition or training for ⩾1 day.
[b] All acute (missing ⩾1 day of competition/training) and overuse injuries.
[c] All injuries.
[d] Head injuries.
[e] Mean (range).
[f] Spleen injuries.
[g] Spine injuries.
[h] Death.
[i] Per 1,000 snowboarder-days.
[j] Per 1,000 snowboarder-visits.

1974). The Glasgow Coma Scale (GCS) assesses brain injury and ranges from 3 to 15 based on eye-opening, verbal, and motor response; a lower GSC indicates a more severe injury (Jennett 2002).

Self-Reported Injuries

Among World Cup athletes, the distribution of injury severity was quite similar: AIS = 1: 38% to 47%, AIS = 2: 47% to 61%, and AIS = 3: 1% to 6% (Torjussen & Bahr 2005, 2006).

Ski Patrol Reports

Bergstrøm et al. (1999) reported a mean ISS of 3.2.

Medical Clinics and Emergency Department Reports

Geddes and Irish (2005) reported a mean length of stay (LOS) of 5.1 days (SD 2.1). Machold et al. (2000) examined those presenting to a medical clinic or emergency department and reported that 10.6 injuries per 1,000 snowboarder-days required medical attention, with a hospital admission rate of 1.8 per 1,000 snowboarder-days.

Hospital Admissions and Trauma Registry Reports

The mean LOS ranged from 2.9 (Sacco et al. 1998) to 20.4 (Hentschel et al. 2001) days, with the longest mean LOS for head injury. Skokan et al. (2003) reported that the ISS ranged from 8 to 11, but 42% had an ISS >15, and 39% had a GCS <8. Prall et al. (1995) reported a mean GCS of 15 (range, 12–15) and Hentschel et al. (2001) found that 36% of snowboarders had a GCS of 14 to 15. Fatality rates have been reported from 0.23 (Sacco et al. 1998) to 0.46 (Shealy et al. 2000) per (1,000,000) snowboarder-days.

Injury Type by Anatomical Location

Table 29.5 describes the percent distribution of the most frequent specific injuries.

Self-Reported Injuries

Ronning et al. (2001) reported a wrist fracture rate of 0.99 per 1,000 snowboarder-days and Wakahara et al. (2006) found a spinal fracture rate of 0.05 per 1,000 snowboarder-days. In a prospective study of World Cup athletes, the most common injuries were back contusions (19%), knee sprains (9%), and shoulder dislocations (9%) (Torjussen & Bahr 2005).

Ski Patrol Reports

Wrist fractures were identified as the most frequent injury (range, 14–31%) reported to ski patrols (Fischler & Rothlisberger 1996; Lamont 1995). Ankle/foot sprains accounted for 24% of the injuries, and ankle fractures represented 19% (Lamont 1995).

Medical Clinics and Emergency Department Reports

The most common injury was wrist fracture (14 of 16 studies), ranging from 10% to 54%. Knee sprains accounted for 9% to 15% of injuries (Abu-Laban 1991; Ganong et al. 1992; Warme et al. 1995; Ueland & Kopjar 1998), followed by wrist sprains (4–12%) (Ueland & Kopjar 1998; Idzikowski et al. 2000; Corra et al. 2004). Ankle fractures ranged from 3% to 11% (Ganong et al. 1992; Janes & Fincken 1993; Warme et al. 1995; Janes & Abbot 1999). Concussions represented 8% to 15% of injuries (Chow et al. 1996; O'Neill & McGlone 1999; Drkulec & Letts 2001).

Hospital Admissions and Trauma Registry Reports

Concussions (24%) were the most common injury in the study by Skokan et al. (2003), while wrist fractures were the most common in the study by Sacco et al. (1998).

Economic Cost

No study evaluated the economic cost of snowboard injury.

Summary

Regardless of the injury definition, the most common injury types were fractures and sprains/strains. Knee sprains were common among elite athletes and those presenting to a medical clinic or ED. Concussion was the most frequent diagnosis among snowboarders admitted to the hospital.

Table 29.5 Percent distribution of the most frequent specific injuries reported.

Study	Most Frequent	Second Most Frequent	Third Most Frequent
Self-Reported Injuries			
Torjussen & Bahr (2005) (n = 32 injuries)[a]	Back contusions, 19%	Knee sprains, 9%	Shoulder dislocation, 9%
Ski Patrol–Reported Injuries			
Ekeland & Rodven (2006) (n = 3,016)[b]	Lower-leg fracture, 1%[c]		
Fischler & Rothlisberger (1996) (n = 512)[b]	Radius fracture, 14%	UE dislocation, 9%	
Lamont (1995) (n = 379)[b]	Distal radius fracture, 31%	Ankle/foot sprain, 24%	Ankle fracture, 19%
Injuries Presenting to a Medical Clinic, Emergency Department, or Hospital			
Abu–Laban (1991) (n = 132 injuries)[b]	Ankle sprain, 20%	Knee sprain, 14%	Wrist fracture, 10%
Chow et al. (1996) (n = 390 injuries)[b]	Radius/ulna fracture, 24%	UE dislocation, 13%	Head concussion, 8%
Corra et al. (2004) (n = 293)[b]	Forearm/wrist fracture, 20%	Cervical sprain/vertebral contusions (without fracture), 16%	Wrist sprain, 12%
Dohjima et al. (2001) (n = 2574 injuries)[b]	Radius fracture, 18%	Shoulder dislocation, 9%	Elbow dislocation, 5%
Drkulec & Letts (2001) (n = 118 injuries[b]	Distal radius fractures, 45%	Cerebral concussion, 8%	Wrist sprain, 7%
Ferrera et al. (1999) (n = 71)[b]	Wrist fracture, 14%	Vertebral fracture, 11%	Intracranial hemorrhage, 10%
Ganong et al. (1992) (n = 415)[b]	Wrist fracture, 19%	Knee sprain, 15%	Ankle fracture, 7%
Idzikowski et al. (2000) (n = 7,430)[b]	Wrist fracture, 16%	Wrist sprain, 4%	Clavicle facture, 4%
Janes & Fincken (1993) (n = 937 injuries)[b]	Radius/ulna fracture, 20%	Tibia fracture, 4%	Malleolar ankle fracture, 4%
Janes & Abbot (1999) (n = 4,390 injuries)[b]	Distal radius fracture, 16%	Spine strain/sprain, 3%	Talus fracture, 3%
Made et al. (1995) (n = 43)[b]	Distal radius fracture, 21%		

Matsumoto et al. (2002) (n = 7,051 injuries)[b]	Wrist fracture, 17%	Shoulder dislocation, 6%	Clavicle fracture, 4%
Matsumoto et al. (2004) (n = 864 injuries)	Distal radius fracture, 86%	Forearm fracture, 6%	
O'Neill & McGlone (1999) (n = 273)	Concussion, 15%		
Ueland & Kopjar (1998) (n = 506)[b]	Lower arm/wrist/hand fracture, 21%	Lower arm/wrist/hand sprain, 11%	Knee/lower-leg sprain, 9%
Warme et al. (1995) (n = 47 injuries)[b]	Medial cruciate ligament tear, 13%	Ankle sprain, 11%	Ankle/foot fracture, 11%
Injuries Admitted to the Hospital			
Sacco et al. (1998) (n = 40)[b]	Radius/ulna fracture, 12.5%		
Skokan et al. (2003) (n = 26)[b]	Concussion, 24%	Femoral fracture, 13%	Spleen laceration, 8%
Injuries Reported for Insurance Coverage			
Pigozzi et al. (1997) (n = 106)[b]	Knee sprains, 13%	Forearm contusion, 8%	Hand fracture, 8%
Injury Setting Not Reported			
Oberthaler et al. (1995) (n = 437 injuries)[b]	Distal radius fracture, 39%	Knee sprain, 14%	

UE = upper extremity.
[a] Any acute injury causing cessation of participating in competition or training for ⩾1 day.
[b] All injuries.
[c] Only one specific injury was reported.

What Are The Risk Factors?

Intrinsic Factors

Age

In the case series by Xiang et al. (2005), the rate for injuries treated in an ED was lower for snowboarders aged 18 to 24 years (13.5 per 1,000 participants) than those <18 years of age (10–13 yr, 15.9 per 1,000 participants; 14–17, 15.0; tests of significance not performed).

Sex

Emery et al. (2006) found women had a higher rate of self-reported injures than men (260 vs. 220 per 1,000 participants per year; no statistical tests reported), similar to Shealy and Ettlinger (1996) (4.1 per 1,000 snowboarder-days vs. 2.8; no statistical tests reported). Boldrino and Furian (1999) found that men were less likely to sustain an injury requiring hospitalization than women (odds ratio [OR], 0.6; 95% confidence interval [CI], 0.4–0.9). Ronning et al. (2001) and Idzikowski et al. (2000) found no difference in injury rate by sex.

Experience

Langran and Selvaraj (2004) found that first-time snowboarders were more likely to sustain an injury reported to the ski patrol than those with more experience (OR, 2.6; 95% CI, 1.8–3.6). Machold et al. (2000) reported that children snowboarding for the first time versus >50 times were at higher risk for injury requiring medical attention (OR, 8.3; 95% CI, not reported). Ronning et al. (2001) noted that snowboarders with <6 days of experience were more likely to suffer an ED-reported injury than those with more experience (OR, 3.53; 95% CI, 1.80–6.96). The medical clinic injury rate was higher (per 1,000 days) among beginners in the study by Shealy and Ettlinger (1996) (beginner: men, 11.2; women, 11.7; intermediate: men, 2.2; women, 2.0; advanced: men, 0.8; women, 0.6; tests of significance not performed). Boldrino and Furian (1999) studied injuries requiring hospitalization and reported that beginners were more likely to be injured (OR, 2.8; 95% CI, 1.7–4.5).

Extrinsic Factors

Terrain Parks

Goulet et al. (2007) showed a greater risk of severe injuries to the UE (OR, 1.5; 95% CI, 1.3–1.7) and LE (OR, 1.3; 95% CI, 1.1–1.5) reported to the ski patrol in snow parks as compared with traditional slopes.

Professional Instruction

Langran and Selvaraj (2004) reported that taking professional instruction was significantly associated with an *increased* risk of medical clinic- or ED-reported injury among first-day snowboarders (OR, 6.6; 95% CI, 2.3–19.3). However, Boldrino and Furian (1999) found no relationship between formal instruction and hospital admission.

Own Equipment

Boldrino and Furian (1999) reported that using one's own equipment was associated with a significantly decreased risk of hospital admission as compared with using rental equipment (OR, 0.3; 95% CI, 0.2–0.5). Ronning et al. (2001) also found a lower risk of injury among snowboarders who used their own equipment (OR, 0.4; 95% CI, 0.2–0.6) but Langran and Selvaraj (2004) found no difference in medical clinic- or ED-reported injury risk by equipment ownership.

Events

Torjussen and Bahr (2006) found higher injury rates in Big Air, boardercross, and half-pipe events (11.6 to 15.9 per 1,000 snowboarder-days) compared with giant slalom and parallel slalom (1.5 to 2.7 per 1,000 days). The results were consistent when examined per 1,000 competition runs (no statistical tests reported).

Summary

The effect of professional instruction on the risk of injury is not clear. However, using a terrain park and renting equipment were independently associated with injury.

What Are the Inciting Events?

Injury Rate by Inciting Events

Shealy et al. (2000) studied recreational snowboarders who suffered an immediate traumatic death within bounds of the ski area. The fatality rate was 0.20 per million participant-visits (MPV) for impact against a fixed object or a person, 0.08 per MPV for impact with snow surface, and 0.03 per MPV for any other mechanism.

Proportions by Injury Mechanism

Self-Reported Injuries

Emery et al. (2006) reported that 68% of recreational snowboarding injuries resulted from a noncontact mechanism, while 25% were caused by a collision against an object. For injuries in World Cup competitions, Torjussen and Bahr (2006) reported that 97% of injuries in the half-pipe event and 100% in the Big Air Event occurred when falling at landing (Figure 29.1); falling at an obstacle caused 52% of snowboardcross injuries. Collisions with competitors were frequent in snowboardcross (44%), while falling between the gates was common in the slalom and giant slalom (57%).

Figure 29.1 Falling on landing is the most common mechanism for injury in half-pipe competition.
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Ski Patrol Reports

Hagel et al. (2005a) reported that 56% of UE injuries resulted from a fall and that 43% followed a collision or a jump. The proportion of all injuries due to a fall ranged from 10% to 17.6%, while those due to a collision ranged from 4% to 15% (Davidson and Laliotis 1996; Hagel et al. 1999; Ekeland and Rodven 2000; Bridges et al. 2003).

Medical Clinics and Emergency Department Reports

Between 50% and 93% of injuries presenting to medical clinics or EDs resulted from a fall (Ferrara et al. 1999; Sasaki et al. 1999a; Idzikowski et al. 2000; Machold et al. 2000; Ronning et al. 2000; Matsumoto et al. 2002; Made & Elmqvist 2004; Yamagami et al. 2004; Xiang et al. 2005). Jumping was the mechanism in 26% to 41% of all injuries (Chow et al. 1996; Nakaguchi et al. 1999; Fukuda et al. 2001; Matsumoto et al. 2004; Geddes and Irish 2005). Yamakawa et al. (2001) reported that jumping (55%) and falling (26%) were the main mechanisms of spinal injuries.

Hospital Admissions and Trauma Registry Reports

Between 40% and 70% of all hospital admissions resulted from falling (Prall et al. 1995; Boldrino & Furian 1999; Shorter et al. 1999; Skokan et al. 2003). Collision with an object represented 12% to 46% of injuries. Tarazi et al. (1999) found jumping (77%) & falling (19%) to be the most frequent mechanisms of spinal injury. Hentschel et al. (2001) reported that head injuries resulted from falling (57%), colliding with an object (29%), and jumping (14%), similar to the results of Levy et al. (2002) for traumatic brain injury (falling, 58%; collision with an object, 34%).

Summary

Falls accounted for 19% to 93% of all injuries and jumping for 10% to 77%. Collisions accounted for approximately 10% to 35% of injuries. Among elite, competitive athletes, the injury mechanism is event-specific.

Injury Prevention

Wrist Guards

Regardless of injury definition or study design, all studies examining the relationship between wrist guards and wrist injury found a statistically significantly lower risk among those using wrist guards (Idzikowski et al. 2000; Machold et al. 2000, 2002; Ronning et al. 2001; O'Neill 2003; Hagel et al. 2005a). Odds or rate ratios ranged from 0.04 (O'Neill 2003) to 0.48 (Idzikowski et al. 2000). Hagel et al. (2005a) found a nonsignificant association between wrist guard use and elbow and shoulder injuries (OR, 2.4; 95% CI, 0.7–7.8).

Helmets

As with wrist guards, the studies examining the relationship between helmets and head injuries have indicated a protective effect (Johnson, Mohtadi and Sasyniuk 2000; Macnab et al. 2002; Ekeland et al. 2004; Sulheim et al. 2006) (although not statistically significant in Macnab et al. [2002], and Ekeland et al. [2004] did not provide confidence intervals). Odds ratios ranged from 0.2 to 0.6, indicating a 40% to 80% reduction in head-injury risk with helmet use.

Education

Levy et al. (2007) undertook a social marketing campaign about helmet effectiveness, loaning free helmets with equipment rental, and giving instructors free helmets to wear while teaching. The campaign had a positive impact on helmet acceptance (55 of 60 accepted helmets). The authors concluded that helmet use can be increased.

Machold et al. (2000) exposed children on a school sports week to a fall impact training program and concluded that there was no reduction in wrist injuries requiring medical attention, despite special falling instructions (1.7% with training vs. 1.1% without training).

Josse and Cusimano (2006) evaluated the impact of the "A Little Respect" video about the Alpine responsibility code, appropriate ski attire, following trail signs, and appropriate actions if an injury occurred or was encountered. The authors reported that students who watched the video displayed higher levels of safety knowledge than control subjects, demonstrating a positive learning trend, although the result was not statistically significant.

Summary

Wrist guards and helmets are effective at reducing wrist and head injuries, respectively. The role of safety education requires further study.

Further Research

1. Future research should use comparative and analytical study designs, such as a cohort, case–control, case–crossover, or clinical trials. Cohort studies should be used to determine injury rates among closed populations at higher risk for injury in a manner similar to O'Neill and McGlone (1999). The case–control study design has been useful for examining the role of protective equipment and would be excellent to determine whether helmets influence the risk of cervical spine injury. The case–crossover design is well suited for examining transient exposures, such as the risk of injury associated with different features in terrain parks. Cluster randomized, controlled trials can be used to examine the effectiveness of educational programs, in which clusters are formed by lesson group within a ski area. Research methods can be improved by providing a clear definition of a reportable injury. Additional studies examining both intrinsic (e.g., fitness levels) and extrinsic (e.g., weather, snow conditions, terrain) risk factors are required.

2. Terrain parks are gaining popularity among skiers and snowboarders and include many human-made obstacles and jumps that may increase injury risk (Goulet et al. 2007). An epidemiologic study has yet to be conducted that examines the injury rates on the various features in the terrain park equipment.
3. There are many variations of snowboarding equipment that have yet to be evaluated. For instance, it is unknown whether the injury rates are similar for race boards versus freestyle boards, ratchet bindings versus step-ins, and forward, Alpine, duck, and flat stance.

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References

Abu-Laban, R.B. (1991) Snowboarding injuries: an analysis and comparison with alpine skiing injuries. *Canadian Medical Association Journal* **145**(9), 1097–1103.

Baker, S.P., O'Neill, B., Haddon, W., Jr. & Long, W.B. (1974) The Injury Severity Score: a method for describing patients with multiple injuries and evaluating emergency care. *Journal of Trauma* **14**, 187–196.

Bergstrøm, K.A., Askild, O., Jorgensen, N.A. & Ekeland, A. (1999) Evaluation of skiing injuries by Injury Severity Score. *Scandinavian Journal of Medicine & Science in Sports* **9**(2), 110–113.

Biasca, N., Battaglia, H., Simmen, H.P., Disler, P. & Trentz, O. (1995) [An overview of snow-boarding injuries] [German]. *Unfallchirurg* **98**(1), 33–39.

Bladin, C., Giddings, P. & Robinson, M. (1993) Australian snowboard injury data base study: a four-year prospective study. *American Journal of Sports Medicine* **21**(5), 701–704.

Boldrino, C. & Furian, G. (1999) Risk factors in skiing and snowboarding in Austria. In: *Skiing Trauma and Safety: 12th volume, ASTM STP 1345* (Johnson, R.J., ed.) American Society for Testing and Materials, West Conshohocken, PA, pp. 166–174.

Bridges, E.J., Rouah, F. & Johnston, K.M. (2003) Snowblading injuries in Eastern Canada. *British Journal of Sports Medicine* **37**(6), 511–515.

Calle, S.C. & Evans, J.T. (1995) Snowboarding trauma. *Journal of Pediatric Surgery* **30**(6), 791–794.

Chow, T.K., Corbett, S.W. & Farstad, D.J. (1996) Spectrum of injuries from snowboarding. *Journal of Trauma-Injury Infection and Critical Care* **41**(2), 321–325.

Committee on Injury Scaling. (1980) *The Abbreviated Injury Scale 1980 revisions*. American Association for Automotive Medicine, Morton Grove, IL.

Corra, S., Conci, A., Conforti, G., Sacco, G. & De Giorgi, F. (2004) Skiing and snowboarding injuries and their impact on the emergency care system in South Tyrol: a retrospective analysis for the winter season 2001–2002. *Injury Control and Safety Promotion* **11**(4), 281–285.

Crim, J.R. (2003) Winter sports injuries The 2002 Winter Olympics experience and a review of the literature. *Magnetic Resonance Imaging Clinics of North America* **11**(2), 311–321.

Davidson, T.M. & Laliotis, A.T. (1996) Snowboarding injuries, a four-year study with comparison with alpine ski injuries[see comment]. *Western Journal of Medicine* **164**(3), 231–237.

Dohjima, T., Sumi, Y., Ohno, T., Sumi, H. & Shimizu, K. (2001) The dangers of snowboarding: a 9-year prospective comparison of snowboarding and skiing injuries. *Acta Orthopaedica Scandinavica* **72**(6), 657–660.

Drkulec, J.A. & Letts, M. (2001) Snowboarding injuries in children. *Canadian Journal of Surgery* **44**(6), 435–439.

Ekeland, A. & Rodven, A. (2000) Injuries in alpine skiing, telemarking, and snowboarding. In: *Skiing Trauma and Safety: 13th volume ASTM STP 1397* (Johnson, R.J., Zucco, P. & Shealy, J.E., eds.), American Society for Testing Materials, West Conshohocken, PA, pp. 87–94.

Ekeland, A. & Rodven, A. (2006) Injury types in alpine skiing and snowboarding related to age groups. *Knee Surgery, Sports Traumatology, Arthroscopy* **14**, 102.

Ekeland, A., Sulheim, S. & Rodven, A. (2004) Injuries in Norwegian ski resorts 2000–2002. *Knee Surgery, Sports Traumatology, Arthroscopy* **12**(2), 169

Emery, C.A., Meeuwisse, W.H. & McAllister, J.R. (2006) Survey of sport participation and sport injury in Calgary and area high schools. *Clinical Journal of Sports Medicine* **16**(1), 20–26.

Federiuk, C.S., Zechnich, A.D. & Vargyas, G.A. (1997) Telemark skiing injuries: a three-year study. *Wilderness and Environmental Medicine* **8**(4), 204–210.

Ferrera, P.C., McKenna, D.P. & Gilman, E.A. (1999) Injury patterns with snowboarding. *American Journal of Emergency Medicine* **17**(6), 575–577.

Fischler, L. & Rothlisberger, M. (1996) [Comparison between ski and snowboarding accidents: current overview from the ski area Arosa (Switzerland) (1988/89 to 1994/95)] [German]. *Schweizerische Rundschau fur Medizin Praxis* **85**(24), 777–782.

Fukuda, O., Takaba, M., Saito, T. & Endo, S. (2001) Head injuries in snowboarders compared with head injuries in skiers: a prospective analysis of 1076 patients from 1994 to 1999 in Niigata, Japan. *American Journal of Sports Medicine* **29**(4), 437–440.

Gabl, M., Lang, T., Pechlaner, S. & Sailer, R. (1991) [Snowboarding injuries] [German]. *Sportverletzung Sportschaden* **5**(4), 172–174.

Gajdzinska, A., Kunysz, P. & Marciniak, M. (2006). Injuries in modern snowboarding. *Studies in Physical Culture & Tourism* **13,** 133–136.

Ganong, R.B., Heneveld, E.H., Beranek, S.R. & Fry, P. (1992) Snowboarding injuries: a report on 415 patients. *Physician and Sportsmedicine* **20**(12), 114–122.

Geddes, R. & Irish, K. (2005) Boarder belly: splenic injuries resulting from ski and snowboarding accidents. *Emergency Medicine Australasia* **17**(2), 157–162.

Goulet, C., Hagel, B., Hamel, D. & Legare, G. (2007) Risk factors associated with serious ski patrol-reported injuries sustained by skiers and snowboarders in snow-parks and on other slopes. *Canadian Journal of Public Health* **98**(5), 402–406.

Hagel, B., Pless, I.B. & Goulet, C. (2005a) The effect of wrist guard use on upper-extremity injuries in snowboarders. *American Journal of Epidemiology* **162**(2), 149–156.

Hagel, B.E., Pless, I.B., Goulet, C., Platt, R.W. & Robitaille, Y. (2005b) Effectiveness of helmets in skiers and snowboarders: case-control and case crossover study. *British Medical Journal* **330**, 281.

Hagel, B.E., Goulet, C., Platt, R.W. & Pless, I.B. (2004) Injuries among skiers and snowboarders in Quebec. *Epidemiology* **15**(3), 279–286.

Hagel, B.E., Meeuwisse, W.H., Mohtadi, N.G. & Fick, G.H. (1999) Skiing and snowboarding injuries in the children and adolescents of Southern Alberta. *Clinical Journal of Sport Medicine* **9**(1), 9–17.

Hagel, B.E., Pless, B. & Platt, R.W. (2003) Trends in emergency department reported head and neck injuries among skiers and snowboarders. *Canadian Journal of Public Health* **94**(6), 458–462.

Hentschel, S., Hader, W. & Boyd, M. (2001) Head injuries in skiers and snowboarders in British Columbia. *Canadian Journal of Neurological Sciences* **28**(1), 42–46.

Huber, B., Beskind, D.L., Johnson, R.J., Ettlinger, C.F. & Shealy, J.E. (1995) Snowboarding injuries. *Scandinavian Journal of Medicine & Science in Sports* **5**, 116.

Idzikowski, J.R., Janes, P.C. & Abbott, P.J. (2000) Upper extremity snowboarding injuries: ten-year results from the Colorado Snowboard Injury Survey. *American Journal of Sports Medicine* **28**(6), 825–832.

Janes, P.C. & Abbot, P., Jr. (1999) The Colorado snowboarding injury study: Eight year results. In: *Skiing Trauma and Safety: 12th volume, ASTM STP 1345* (Johnson, R.J., ed.) American Society for Testing and Materials, West Conshohocken, PA, pp. 141–149.

Janes, P.C. & Fincken, G.T. (1993) Snowboarding injuries. In: *Skiing Trauma and Safety: 9th International Symposium, ASTM STP 1182* (Johnson, R.J., Mote, C.D., Jr. & Zelcer, J., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 255–261.

Janes, P.C. & Fincken, G.T. (1995) Snowboarding injuries. *Scandinavian Journal of Medicine and Science in Sports* **5**, 115.

Jennett, B. (2002) The Glasgow Coma Scale: history and current practices. *Trauma* **4**, 91–103.

Johnson, K.N., Mohtadi, N.G.H. & Sayniuk, T.M. (2002) The prevalence of protective equipment use and injury prevention in snowboarding. *Clinical Journal of Sport Medicine* **12**(1), 66.

Josse, J.M. & Cusimano, M. (2006) The effect of a skiing/snowboarding safety video on the increase of safety knowledge in Canadian youths—a pilot study. *International Journal of Circumpolar Health* **65**(5), 385–388.

Lamont, M.K. (1995) Ski field injuries: the snowboarders. In: *Skiing Trauma and Safety: 10th volume, ASTM STP 1266* (Mote C.D., Jr., Johnson, R.J., Hauser, W. & Schaff, P.S., eds.), American Society for Testing Materials, Philadelphia, PA, pp. 82–86.

Langran, M. & Selvaraj, S. (2004) Increased injury risk among first-day skiers, snowboarders, and skiboarders. *American Journal of Sports Medicine* **32**(1), 96–103.

Levy, A., Hawkes, A., Hemminger, L. & Knight, S. (2002) An analysis of head injuries among skiers and snowboarders. *Journal of Trauma* **53**(4), 695–704.

Levy, A.S., Hawkes, A.P. & Rossie, G.V. (2007) Helmets for skiers and snowboarders: an injury prevention program. *Health Promotion Practice* **8**(3), 257–265.

Lipskie, T.L., Birkett, N., Pickett, W. & Klassen, T. (2001) Risk for snowboarding and skiing injury. *American Journal of Epidemiology* **153,** S72.

Llorens, N., Espinalt, M. & Vidal, A. (2005) Injury patterns in alpine skiing and snowboarding: a prospective study in Baqueira Beret, Spain. *British Journal of Sports Medicine* **39**(6), 395.

Machold, W., Kolonja, A., Kwasny, O. & Fuchs, M. (1999) [Risk of injuries in snow boarding] [German]. *Sportverletzung Sportschaden* **13**(1), 1–7.

Machold, W., Kwasny, O., Gassler, P., Kolonja, A., Reddy, B., Bauer, E. & Lehr, S. (2000) Risk of injury through snowboarding. *Journal of Trauma-Injury Infection and Critical Care* **48**(6), 1109–1114.

Machold, W., Kwasny, O., Eisenhardt, P., Kolonja, A., Bauer, E., Lehr, S., Mayr, W. & Fuchs, M. (2002) Reduction of severe wrist injuries in snowboarding by an optimized wrist protection device: a prospective randomized trial. *Journal of Trauma Injury Infection and Critical Care* **52**(3), 517–520.

Macnab, A.J. & Cadman, R. (1996) Demographics of alpine skiing and snowboarding injury: lessons for prevention programs. *Injury Prevention* **2**(4), 286–289.

Macnab, A.J., Smith, T., Gagnon, F.A. & Macnab, M. (2002) Effect of helmet wear on the incidence of head/face and cervical spine injuries in young skiers and snowboarders. *Injury Prevention* **8**(4), 324–327.

Made, C. & Elmqvist, L.G. (2004) A 10-year study of snowboard injuries in Lapland Sweden. *Scandinavian Journal of Medicine & Science in Sports* **14**(2), 128–133.

Made, C., Elmqvist, L.G. & Sjukstuga, T. (1995) Snowboarding injuries in Tarnaby/Hemavan 1993–94. *Scandinavian Journal of Medicine & Science in Sports* **5**, 115.

Matsumoto, K., Miyamoto, K., Sumi, H., Sumi, Y. & Shimizu, K. (2002) Upper extremity injuries in snowboarding and skiing: a comparative study. *Clinical Journal of Sport Medicine* **12**(6), 354–359.

Matsumoto, K., Sumi, H., Sumi, Y. & Shimizu, K. (2003) An analysis of hip dislocations among snowboarders and skiers: a 10-year prospective study from 1992 to 2002. *Journal of Trauma* **55**(5), 946–948.

Matsumoto, K., Sumi, H., Sumi, Y. & Shimizu, K. (2004) Wrist fractures from snowboarding: a prospective study for 3 seasons from 1998 to 2001.

Clinical Journal of Sport Medicine **14**(2), 64–71.
Mclennan, J.G. & Mclennan, J.C. (1990) A survey of snowboarding injuries. *Medicine and Science in Sports and Exercise* **22,** S101.
Michaud, P.A., Renaud, A. & Narring, F. (2001) Sports activities related to injuries? A survey among 9–19 year olds in Switzerland. *Injury Prevention* 7(1), 41–45.
Moore, T. (2000) Snowboarding injuries. *British Journal of Sports Medicine* **34**(2), 79.
Nakaguchi, H., Fujimaki, T., Ueki, K., Takahashi, M., Yoshida, H. & Kirino, T. (1999) Snowboard head injury: prospective study in Chino, Nagano, for two seasons from 1995 to 1997 [see comment]. *Journal of Trauma-Injury Infection & Critical Care* **46**(6), 1066–1069.
Oberthaler, G., Primavesi, C., Niederwieser, B. & Hertz, H. (1995) [Snowboarding accidents 1991 to 1994—an analysis] [German]. *Sportverletzung Sportschaden* **9**(4), 118–122.
Olympic Movement (2007). Official website —Snowboard. URL www.olympic.org/uk/sports/programme/disciplines_uk.asp?DiscCode=SB [accessed December 2, 2007]
O'Neill, D.F. & McGlone, M.R. (1999) Injury risk in first-time snowboarders versus first-time skiers. *American Journal of Sports Medicine* **27**(1), 94–97.
O'Neill, D. (2003) Wrist injuries in guarded versus unguarded first time snowboarders. *Clinical Orthopaedics and Related Research* **Apr**(409), 91–95.
Pigozzi, F., Santori, N., Di Salvo, V., Parisi, A. & Di Luigi, L. (1997) Snowboard traumatology: an epidemiological study. *Orthopedics* **20**(6), 505–509.
Pino, E.C. & Colville, M.R. (1989) Snowboard injuries. *American Journal of Sports Medicine* **17**(6), 778–781.
Pogorzelski, A., McCrory, P. & Bladin, C. (2003) Alpine sports injuries in Victoria. *Journal of Science & Medicine in Sport* **6,** 52.
Prall, J.A., Winston, K.R. & Brennan, R. (1995) Severe snowboarding injuries. *Injury* **26**, 539–542.
Robertson, L.S. (1998) *Injury Epidemiology Research and Control Strategies,* 2nd ed., Oxford University Press, New York, NY, p. 32.
Ronning, R., Gerner, T. & Engebretsen, L. (2000) Risk of injury during alpine and telemark skiing and snowboarding: the equipment-specific distance-correlated injury index. *American Journal of Sports Medicine* **28**(4), 506–508.
Ronning, R., Ronning, I., Gerner, T. & Engebretsen, L. (2001) The efficacy of wrist protectors in preventing snowboarding injuries. *American Journal of Sports Medicine* **29**(5), 581–585.
Sacco, D.E., Sartorelli, D.H. & Vane, D.W. (1998) Evaluation of alpine skiing and snowboarding injury in a northeastern state. *Journal of Trauma* **44**(4), 654–659.
SafetyLit. Injury Prevention Literature Update. URL http://www.Safetylit.Org [accessed June 14, 2007]
Sasaki, K., Takagi, M., Ida, H., Yamakawa, M. & Ogino, T. (1999a) Severity of upper limb injuries in snowboarding. *Archives of Orthopaedic and Trauma Surgery* **119**(5–6), 292–295.
Sasaki, K., Takagi, M., Kiyoshige, Y. & Ogino, T. (1999b) Snowboarder's wrist: its severity compared with alpine skiing. *Journal of Trauma Injury Infection and Critical Care* **46**, 1059–1061.
Schrank, C., Gaulrapp, H. & Rosemeyer, B. (1999) [Pattern and risk of injuries of profile athletes in snow boarding] [German]. *Sportverletzung Sportschaden* **13**(1), 8–13.
Schröcksnadel, P., Burtscher, M., Traweger, C. & Marinell, G. (1995) Accident rate and distribution of injuries in downhill skiers and snowboarders in Austria. *Scandinavian Journal of Medicine and Science in Sports* **5**, 115.
Shealy, J.E. (1993) Snowboard vs. downhill skiing injuries. In: *Skiing Trauma and Safety: 9th International Symposium, ASTM STP 1182* (Johnson, R.J., Mote, C.D., Jr. & Zelcer, J., eds.), American Society for Testing and Materials, Philadelphia, PA, pp. 241–254.
Shealy, J.E. & Ettlinger, C.F. (1996) Gender-related injury patterns in skiing. In: *Skiing Trauma and Safety: 10th volume, ASTM STP 1266* (Mote, C.D., Jr., Johnson, R.J., Hauser, W. & Schaff, P.S., eds.), American Society for Testing Materials, Philadelphia, PA, pp. 45–57.
Shealy, J.E. & Ettlinger, C.F. (2004) Third end of decade analysis of snow sports injuries in the USA. *Knee Surgery, Sports Traumatology, Arthroscopy* **12**(2), 171.
Shealy, J.E., Ettlinger, C.F. & Buonomo, V. (1997) Epidemiology of snowboarding injuries: 1988 to 1995. In: *Skiing Trauma and Safety: 11th volume.* West Conshohocken, PA, pp. 49–59.
Shealy, J.E. & Sundman, P.D. (1989) Snowboarding injuries on alpine slopes. In: *Skiing Trauma and Safety: 7th International Symposium, ASTM, 1022* (Johnson, R.J., Mote, C.D., Jr. & Binet, M.-H., eds.), American Society for Testing Materials, Philadelphia, PA, pp. 75–81.
Shealy, J.E., Ettlinger, C.F. & Jonson, R.J. (2000) Rates and modalities of death in the US: snowboarding and skiing differences - 1991/92 through 1998/99. In: *Skiing Trauma and Safety: 13th volume ASTM STP 1397* (Johnson, R.J., Zucco, P. & Shealy, J.E., eds.), American Society for Testing Materials, West Conshohocken, PA, pp. 132–138.
Shorter, N.A., Mooney, D.P. & Harmon, B.J. (1999) Snowboarding injuries in children and adolescents. *American Journal of Emergency Medicine* **17**, 261–263.
Siu, T.L.T., Chandran, K.N., Newcombe, R.L., Fuller, J.W. & Pik, J.H.T. (2004) Snow sports related head and spinal injuries: an eight-year survey from the neurotrauma centre for the Snowy Mountains, Australia. *Journal of Clinical Neuroscience* **11**(3), 236–242.
Skokan, E.G., Junkins, E.P., Jr. & Kadish, H. (2003) Serious winter sport injuries in children and adolescents requiring hospitalization. *American Journal of Emergency Medicine* **21**(2), 95–99.
Sulheim, S., Holme, I., Ekeland, A. & Bahr, R. (2006) Helmet use and risk of head injuries in alpine skiers and snowboarders. *Journal of the American Medical Association* **295**(8), 919–924.
Sutherland, A.G., Holmes, J.D. & Myers, S. (1996) Differing injury patterns in snowboarding and alpine skiing. *Injury* **27**(6), 423–425.
Tarazi, F., Dvorak, M.F. & Wing, P.C. (1999) Spinal injuries in skiers and snowboarders. *American Journal of Sports Medicine* **27**(2), 177–180.
Torjussen, J. & Bahr, R. (2005) Injuries among competitive snowboarders at the national elite level. *American Journal of Sports Medicine* **33**(3), 370–377.
Torjussen, J. & Bahr, R. (2006) Injuries among elite snowboarders (FIS Snowboard World Cup). *British Journal of Sports Medicine* **40**(3), 230–234.
Ueland, O. & Kopjar, B. (1998) Occurrence and trends in ski injuries in Norway. *British Journal of Sports Medicine* **32**(4), 299–303.
Wakahara, K., Matsumoto, K., Sumi, H., Sumi, Y. & Shimizu, K. (2006) Traumatic spinal cord injuries from

snowboarding. *American Journal of Sports Medicine* **34**(10), 1670–1674.
Warme, W.J., Feagin, J., Jr., King, P., Lambert, K.L. & Cunningham, R.R. (1995) Ski injury statistics, 1982 to 1993, Jackson Hole Ski Resort. *American Journal of Sports Medicine* **23**(5), 597–600.
Xiang, H., Kelleher, K., Shields, B.J., Brown, K.J. & Smith, G.A. (2005) Skiing and snowboarding related injuries treated in US emergency departments, 2002. *Journal of Trauma Injury Infection and Critical Care* **58**, 112–118.
Yamagami, T., Ishihara, H. & Kimura, T. (2004) Clinical features of snowboarding injuries. *Journal of Orthopaedic Science* **9**(3), 225–229.
Yamakawa, H., Murase, S., Sakai, H., Iwama, T., Katada, M., Niikawa, S., Sumi, Y., Nishimura, Y. & Sakai, N. (2001) Spinal injuries in snowboarders: risk of jumping as an integral part of snowboarding. *Journal of Trauma Injury Infection and Critical Care* **50**(6), 1101–1105.
Zacharapoulos, A.N., Tzanakakis, N. & Mitsou, A. (2004) Injury types in skiing and snowboarding—the Greek experience. *Knee Surgery, Sports Traumatology, Arthroscopy* **12**(2), 169–170.

PART 3

PARALYMPIC SPORTS

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Chapter 30

Paralympic Sports

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Introduction

Paralympic sports have seen an exponential rise in participation and spectator popularity but remain poorly understood not only by the general public but also in the sports medicine arena. The term applies to elite sport competition for people who have physical or visual impairments. Athletes with intellectual disabilities are not currently part of the Paralympic Games and are not included in this literature review.

Sports for people with disabilities have evolved significantly since the first Stoke Mandeville Games took place on the opening day of the 1948 London Olympic Games. Since 1960, a quadrennial Games has been held in the country selected for the Olympic Games when possible (Webborn 1999). In 1976, in Toronto, the Games included visually impaired and amputee athletes for the first time. In 1980, in Arnhem, athletes with physical disabilities not fitting into the historical disability groups ("Les Autres"; French for "the others") or with cerebral palsy were also included. The International Paralympic Committee is the current governing body of the Paralympic movement and organizes both the summer (20 sports) and winter (5 sports) Paralympic Games.

Despite the growth of disability sports participation, little epidemiologic research has been conducted on this population. The purpose of this chapter is to examine the existing literature on injuries in Paralympic sports. A variety of methodologic limitations, which confound the interpretability of the findings, were evident, including lack of a standard definition of reportable injury, short study time frames, poor or absent exposure data, use of self-report surveys that did not include a confirmed medical diagnosis, and small sample sizes. In addition, the unique grouping of sports by disability makes obtaining a clear picture of injury risk and risk factors in Paralympic sports complicated. For example, when investigating the risk of injury related to a particular sport, of the 25 Paralympic sports, some are played by a number of different classes of athletes with disabilities (athletics: spinal-cord-injured, visually impaired, amputees, cerebral palsy), some are unique to particular disability categories (goalball: visually impaired; wheelchair rugby: athletes with quadraplegia), some are modified by rules (judo) or equipment (sit-ski, sledge hockey) for particular classes of athletes, and some involve multiple categories of disability on the same team (basketball). Alternatively, if the investigation is focused on the risks related to a particular class of disability, similar difficulties exist. For example, a lower-limb amputee athlete may compete with a prosthesis for track athletics or volleyball, without a prosthesis for swimming or high jump, or in a wheelchair for sports such as basketball and tennis. Athletes with cerebral palsy may be ambulant or wheelchair users depending on the degree of disability.

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Changes in professionalism and level of participation in disability sports entail a further difficulty in interpreting the available data. In the 1970s and 1980s, it was not uncommon for individual athletes to participate in multiples sports, even at the Paralympic Games. In a survey of 128 athletes with disabilities, Curtis & Dillon (1985) found that 79% were competing in track athletics, 71% in wheelchair basketball, 57% in road racing, and 60% in field events in athletics. This is no longer the case in elite disability sports. Finally, technology in the form of lightweight, high-tensile-strength materials and improved designs for wheelchairs and prostheses for different populations of Paralympic athletes has changed performance parameters and injury-risk characteristics over the past two decades, such that comparisons between injury patterns seen 20 years ago and those seen currently may not be appropriate, and findings from older research articles in this area may not reflect the current position in elite Paralympic sport. Thus, given the preceding issues, a broad overview of injury patterns in Paralympic sports potentially loses sight of risk and risk-factor relationships in specific sport–disability interactions, but the small numbers in any particular combination render analyses and conclusions unstable.

Who Is Affected by Injury?

A comparison of injury rates reported in prospective and retrospective research is shown in Table 30.1. Some studies involved multiple-disability groups and some covered only individual-disability groups; sports surveyed ranged from the full complement of summer Paralympic sports to individual sports. Few studies reported a true incidence rate because of omission of exposure data. Interpretability of the results is also clouded by the failure of researchers to provide the definition of a reportable injury for their studies or by the variation of the definition between studies. Invariably, the definition will influence both the data collected and the risk assessment of the sports studied. For example, several retrospective questionnaire studies recorded minor soft-tissue injuries, such as blisters or abrasions, for which no medical attention was sought, whereas other research, which was based on the organizing committee's medical services at Paralympic Games, did not include minor soft-tissue injuries.

A 2-year prospective study by Ferrara & Buckley (1996) of 319 multiple-disability athletes in summer Paralympic sports produced an overall injury rate of 9.3 per 1,000 hours of exposure; however, no details on specific sports were provided. Allen (2003) surveyed sailors in the International Foundation for Disabled Sailing World Championship, with 24 teams and multiple disability types, and found an injury prevalence of 6.3%.

Studies of winter sports also included variation between reports on single events such as Alpine skiing to all winter Paralympic sports. A multicenter study of injuries occurring in recreational skiers with a disability reported a rate of two injuries per 1,000 skier-days (McCormick 1985). Webborn (2007) reported comparative injury data by sport from two winter Paralympic Games (2002 and 2006) and found similar rates at the two Games in each sport. In Alpine skiing, 13% of competitors presented at the venue medical services or polyclinic with significant injury in 2002, as compared with 12% in 2006. For ice sledge hockey, the prevalence was 14% and 11% of competitors, respectively, and in Nordic skiing, 3% and 4%.

McCormack & Reid (1991) reported the prevalence of injury in basketball (30.9%), track athletics (30.6%), and road racing (12.1%) in a retrospective study of wheelchair athletes. However, blisters and abrasions formed approximately 50% of these injuries, many of which did not require medical treatment.

Reynolds et al. (1994) studied the British team at the 1992 Paralympic Games in Barcelona and found that the percentage of athletes injured during training and competition across 15 different sports ranged from 50% to 90% of all athletes, apart from cycling (17%).

Where Does Injury Occur?

Anatomical Location

Table 30.2 presents the percent distribution of injuries by body region. In studies involving wheelchair athletes, the upper limb, particularly the shoulder, is the most common site of injury, with prevalence for shoulder injury ranging from 19% (McCormack

Table 30.1 Injury rates in disability sports.

Study	Sport	Study Design	No. of Subjects	No. of Injuries	Injuries/100 Participants	Injuries/1,000 hr of Exposure	Injuries/1,000 AEs	Notes
Curtis & Dillon (1985)[a–d]	Athletics, basketball, swimming, road racing	RQ	128	291	228.6	—	—	
McCormick (1985)[a–e]	Alpine skiing	RQ	60	23	38.3	—	—	2/1,000 skier-days
Ferrara & Davis (1990)[a]	Wheelchair sports		19	50	263	—	—	
Burnham et al. (1991)[a–e]	Summer Paralympics	P/R	151	108	71	—	—	
McCormack & Reid (1991)[a–c,e]	19 Wheelchair sports	RQ	90	346	384	—	—	
Richter et al. (1991)[c]	Cerebral palsy sports	P/R	75	27	36	—	—	
Ferrara et al. (1992a)[a,b,d]	Alpine skiing	RQ	68	100	147	—	—	All responders had injuries
Ferrara et al. (1992b)[a–e]	Multisport	RQ	426	137	32	—	—	
Wilson & Washington (1993)[a]	* Athletics track * Athletics field * Swimming	RQ	69 58 35	67 13 32	97 22 91	—	—	
Burnham & Higgins (1994)[a,b]	Wheelchair basketball	RQ	116	189	163	—	—	
Reynolds et al. (1994)[a–e]	Summer Paralympics	RR	203	134	66	—	—	
Taylor & Williams (1995)[a]	Wheelchair racing	RQ	53	38	72	—	—	
Ferrara & Buckley (1996)[a–c,e,f]	Summer Paralympics	PQ	319	128	40.1	9.4	—	
Reeser (1999)[b,e]	Standing volleyball	RQ	41	19	—	—	8.5	
Ferrara et al. (2000)[a–e]	Multisport	P/R	1360	1037	76	—	—	

(continued)

Table 30.1 (*continued*)

Study	Sport	Study Design	No. of Subjects	No. of Injuries	Injuries/100 Participants	Injuries/1,000 hr of Exposure	Injuries/1,000 AEs	Notes
Nyland et al. (2000)[a–d]	Summer Paralympics	P/R	304	254	84	—	—	Soft-tissue injuries only
Webborn & Turner (2000)[a–f]	Summer Paralympics	P/R	244	149	61	—	—	
Allen (2003)[a,b,d]	Sailing	P/R	394	25	6.34	—	—	
Sobiecka (2005)[a–f]	Summer Paralympics	P/R	114	125	109.6	—	—	
Webborn et al. (2006)[a–e]	Winter sports	P/R	416	39	9	—	—	
	* Alpine		* 194	* 24	* 12			
	* Nordic		* 134	* 3	* 2			
	* Sledge hockey		* 88	* 12	* 14			
Webborn (2007)[a–e]	Winter sports	P/R	474	40	8.4	—	—	
	* Alpine		* 190	* 23	* 12			
	* Nordic		* 132	* 5	* 6.6			
	* Sledge hockey		* 112	* 12	* 13.4			
	* Curling		* 40	* 0	* 0			
Zimmer (2007)[a–e]	Summer Paralympics	RR	208	116	56	—	—	Includes medical conditions and injuries

AE = athlete exposures; P = prospective; Q = questionnaire; R = retrospective.

[a] Spinal cord–related disability.
[b] Amputee.
[c] Cerebral palsy.
[d] Les Autres.
[e] Visually impaired.
[f] Intellectual disability.

Table 30.2 Percent distribution of injury by anatomical location.

Study	Sports	Head	Neck/ Thoracic	Chest/ Trunk	Lumbar Spine	Shoulder	Hand	Other Upper Limb	Hip	Thigh	Knee	Lower Leg	Foot/ Ankle
	Summer												
Ferrara & Davis (1990)[a]	Track and field, 63.6% Swimming, 22.7% Table tennis, 9.1% Shooting, 4.5%	0	18	0	0		58				22		
Burnham et al. (1991)[a–e]	Paralympic sports	0	5	0	8	38	11	4	18		2	6	8
McCormack & Reid (1991)[a–d]	19 Wheelchair sports	5	1	2	2	19	35	25			7		
Ferrara et al. (1992a)[a–e]	Paralympic sports	3 4 0	8 6 6	6 3 4	0 0 0	15 17 40	11 14 4	4 12 21		6 7 3	10 21 12	26 15 6	11 1 4
Reynolds et al. (1994)[a–e]	Paralympic sports	0	17	3	11	9	8	3	0	5	5	0	0
Ferrara & Buckley (1996)[a–d,f]	Paralympic sports		13	16	0	17	12	17		7	9	6	5
Reeser (1999)[c,e] (Incomplete data)	Standing volleyball	0	0	0	0	18	18	0	0	0	14	0	21
Webborn & Turner (2000)[a–f]	Paralympic sports	1	33	1	13	7	8	7	7	3	3	6	11

(*continued*)

Table 30.2 (*continued*)

Study	Sports	Head	Neck/ Thoracic	Chest/ Trunk	Lumbar Spine	Shoulder	Hand	Other Upper Limb	Hip	Thigh	Knee	Lower Leg	Foot/ Ankle
Ferrara et al. (2000)[a–e]	Multisport	5	33	0	0	42	0	7	1	0	5	6	0
Nyland et al. (2000)[a,c,d,e]	Paralympic sports	0	5	0	8	26	9	4		14	11	2	18
		0	19	0	8	17	4	10		21	17	11	8
		0	7	0	14	7	5	4		4	5	4	22
		0	8	0	9	18	5	24		1	0	1	5
Allen (2003)[a,c,e]	Sailing	0		20			60				20		
	Winter												
Ferrara et al. (1992b)[a,c,e]	Alpine skiing	1	11	1	0		51				36		
Webborn et al. (2006)[a–e]	Winter sports	10	5	3	0	21	8	18			23	10	3
Webborn (2007)[a–e]	Winter sports	5	8	10	3	31	3	21	3	0	8	8	3

[a] Spinal cord–related disability.
[b] Visually impaired.
[c] Amputee.
[d] Cerebral palsy.
[e] Les Autres.
[f] Intellectual disability.

Figure 30.1 High forces and extreme range of motion may contribute to shoulder injury in wheelchair athletes. © IOC/Yo NAGAYA.

& Reid 1991) across multiple wheelchair sports to 72% in female wheelchair basketball players (Curtis & Black 1999). However, Webborn and Turner (2000) noted in their report on 244 British athletes seen over a 4-week period – including the build-up to and competition in a summer Paralympic Games – that although the shoulder was the most common site of pain in wheelchair athletes (30%), the cervical and thoracic spine (59% & 8%, respectively) were the actual sites of pathology (resulting in referred pain to the shoulder), as compared with 33% of specific shoulder pathology (Figure 30.1).

Reeser (1999) identified the foot-and-ankle region as the most common site of injury (21%), followed by the shoulder (18%), wrist and hand (18%), and the knee (14%), in standing volleyball players, comprised of athletes with upper-limb and lower-limb impairments including amputation; however, the distribution of injury locations was not related to the type of disability in this study.

Webborn et al. (2006) noted that lower-limb fractures were frequent in spinal cord–injured ice sledge hockey athletes and in standing athletes in Alpine skiing. Athletes in seated classes had more injuries to the upper limb. Injuries to the head and neck in ice sledge hockey and Alpine events (13–15%) were also common.

Environmental Location

Few studies have addressed the issue of injury distribution across training and competition. Reeser (1999) noted that 64% of injuries occurred in training for standing volleyball for amputees and Les Autres athletes, while Webborn and colleagues (2006, 2007) found approximately 38% of injuries from competition across Alpine and Nordic skiing and sledge hockey in two consecutive Winter Games (however, between 23% and 38% of total reported injuries in each study did not specific location).

When Does the Injury Occur?

Injury Onset

Table 30.3 presents the percent distribution of acute and chronic injuries in disability sports. It appears that there is approximately a 60:40 ratio of acute to chronic injuries reported in the literature for most summer Paralympic sports. However, this may reflect when the injury data were collected, with competition surveys reporting more acute injuries (Reeser 1999; Ferrara et al. 2000; Nyland et al. 2000) and longitudinal surveys reporting more chronic injuries (Curtis & Dillon 1985; Ferrara et al. 1992).

Chronometry

There are no studies that detail information on, for example, time into practice, time of day, time of season, or periods in games when injuries occur. Further sport-specific research is required in this area.

Table 30.3 Percent distribution of injury onset—acute versus chronic.

Study	Sample	Injuries	M:W (%)	**Summer Sports**	Acute	Chronic
Curtis & Dillon (1985)[a,c,d,e]	1200	128	79:21	Wheelchair sports	40	60
Ferrara & Davis (1990)[a]	19	19	53:47	Wheelchair sports	65	35
Burnham et al. (1991)[a–e]	151	108	NR	Summer Paralympics	49	51
Richter et al. (1991)[d]	75	27	NR	Summer Paralympics	73	27
Ferrara et al. (1992a)[a–e]	426	137	NR	Summer Paralympics	46	54
Taylor & Williams (1995)[a]	53	38	77:23	Wheelchair racing	41	59
Reeser (1999)[c,e]	89	41	All Male	Standing volleyball	60	40
Ferrara et al. (2000)[a–e]	1360	1037	NR	Multisport	77	23
Nyland et al. (2000)[a,c,d,e]	304	254	NR	Summer Paralympics	67	33
				Mean	58	42
				Winter Sports		
Ferrara et al. (1992)[a,c,e]	68	68	78:22	Alpine skiing	50	50
Webborn et al. (2006)[a–e]	194	24	79:21	Alpine skiing	91	9
	134	12		Ice sledge hockey	83	17
	88	3		Nordic skiing	50	50
Webborn (2007)[a–e]	190	23	79:21	Alpine skiing	78	22
	112	12		Ice sledge hockey	64	36
	132	5		Nordic skiing	80	20
				Mean	71	29

M = men; NR = Not Recorded; W = women.
[a] Spinal cord–related disability.
[b] Visually impaired.
[c] Amputee.
[d] Cerebral palsy.
[e] Les Autres.

What Is the Outcome?

Injury Type

Table 30.4 presents the percent distribution of injury by type. Overall, it appears that strains (mean, 25.4%; range, 4–60%) and sprains (mean, 22.8%; range, 3.7–48%) are the most common injury types. However, the use of self-report data in the majority of the studies raises questions about the validity of injury classifications in these works. The studies by Burnham et al. (1991) and Webborn et al. (2006), in which physician or therapist diagnosis was the basis for classification, may be considered more accurate. Finally, some authors classified medical conditions and illnesses in the category of musculoskeletal injury. Hence the percentages of injuries that are actually musculoskeletal may not total 100% in Table 30.4.

Time Loss

Previously presented data show that a high percentage of self-reported injuries are relatively minor, in that no medical attention is sought. Ferrara and Buckley (1996) developed an "Athletes with Disabilities Injury Registry," which tracked 319 athletes reporting 128 injuries and classified time lost due to injury as minor (0–7 days), moderate (8–21) ,or major (≥22). Across the different disability groups represented they found that minor injuries accounted for 52% of all injuries, while moderate and major injuries accounted for 29% and 19%, respectively. Illness and disability conditions accounted for 20% of all time lost. Of the musculoskeletal injuries resulting in major time loss, the majority were related to the shoulder, wrist, or hand, but more specific diagnoses for these problems were not reported. The mean number of days

Table 30.4 Percent distribution of injury by type.

Study	Sport	Diagnosis	Subjects	Injury Type as Percentage of All Injuries												
				Sprain	Strain	Tendonitis	Bursitis	Blisters	Abrasions/ Lacerations	Fractures	Hand neural	Dental	Head	Joint	Pressure Sore	Contusion
Curtis & Dillon (1985)[a,c,d,e]	Wheelchair sports	Self-report	128/1200		33			18	17	5	5	1		5	7	
Ferrara & Davis (1990)[a]	Wheelchair sports	Self-report	19	48	4			6	22	6						10
McCormack & Reid (1991)[a–d]	Wheelchair sports	Self-report	90	16.3					22.5	2			2	0.6		7.8
Burnham et al. (1991)[a–e]	Summer Paralympics	Physician/ therapist	124/151	3.7	22.2				5.5							
Ferrara & Buckley (1996)[a–d,f]	Summer Paralympics	Self-report	128/319	14	60				7	8		2	8			
Reeser (1999)[c,e]	Standing volleyball	Self-report	41	32	23	14	9									
Webborn et al. (2006)[a–e]	Winter paralympics	Physician/ therapist	39/416	23	18	13			21	15			3	8		

Data incomplete in some studies.

[a] Spinal cord related–disability.
[b] Visually impaired.
[c] Amputee.
[d] Cerebral palsy.
[e] Les Autres.
[f] Intellectual disability.

lost from training because of shoulder injuries was 32 days, and for hand and finger injuries, 27 days.

Webborn et al. (2006) reported that at least 27% of traumatic injuries, including anterior cruciate ligament rupture, concussion, and upper- and lower-limb fractures, at the 2002 winter Paralympic Games were severe enough to affect the athletes' ability to continue to play.

Clinical Outcome

There is a lack of studies that address the issue of clinical outcomes from disability sports injuries. No studies have reported any catastrophic injuries.

Economic Cost

No studies have attempted to address the issue of the economic cost of injuries in Paralympic sports.

What Are the Risk Factors?

Given that the nature of injury risk is inherent in the particulars of each sport and that the Paralympics encompasses 25 different events, it is difficult from the limited data available to delineate risk factors in individual sports. Ferrara and Peterson (2000) classified summer Paralympic sports as either low or high risk for injury based on the observation that "significant injuries such as fractures and dislocations appeared to have a very low incidence" and suggested that this was due to there being few contacts sports in the summer Paralympic program. However, injuries to the shoulder, hand, and fingers have been associated with significant time loss, and these injuries are most common in endurance wheelchair sports, although athletics was classified as a low-risk sport. Despite these categorizations no data-based studies have examined the relationship between particular sports and the risk of specific injuries.

Intrinsic Factors

Few studies have attempted to quantify intrinsic risk factors, such as age, sex, physical fitness or previous injury, in Paralympic sports. Webborn and colleagues (2006, 2007) reported no difference in the prevalence of injuries over two consecutive winter Paralympic Games for men (8% and 9%, respectively) and women (8% for both).

In a study of British wheelchair racers, Taylor & Williams (1995) found no association between distance pushed per week, the number of weight-training sessions, or the length of time athletes had been involved in wheelchair racing and injury. However, athletes who returned to training before an existing injury was resolved were more likely to have a recurrence.

Burnham & Higgins (1994) stated that time-loss injuries in wheelchair basketball players were associated with training load (for days per week).

Extrinsic Factors

Extrinsic risk factors such as the protective equipment, adapted sports equipment, and environment variations are extensive in Paralympic sports and are too detailed to discuss individually in this chapter. Even the wheelchair, one of the most common pieces of equipment, has multiple design characteristics depending on the sport and the type of disability involved. For example, the seating position for wheelchair racing is markedly different from that for wheelchair basketball, as is the propulsion design. In wheelchair racing, a smaller-diameter push rim is used to allow rapid revolutions while in sports such as tennis or basketball, maneuverability is paramount and the push rim is at the periphery of the wheel. In addition, the technical demands of the sport determine whether protective gloves or padding can be used, as in wheelchair racing, or whether manual dexterity needs to be preserved, as in basketball. Finally, the level of disability will impact the specific setup of a chair, depending on the degree of trunk control and support required (Yang et al. 2006). Similarly lower- and upper-limb prostheses have been developed for sport-specific function, and new designs and materials have changed the function and energy storage/return characteristics of the prostheses, which may impact injury risk. For example, Buckley (1999) argued that differential energy return in a lower-limb prosthesis increases the likelihood of acute excessive forces in the normal ankle, which may result in injury. Each of these factors related to wheelchair and prostheses performance modifies the forces applied on the athletes and may be related to differences in injury risk. However, no studies have been found that analyze any of these issues as risk factors for Paralympic athletes.

Taylor & Williams (1995) found no difference in injury risk between wheelchair athletes with a structured training program or a coach (or both), and those without. Fullerton et al. (2003) showed a significantly lower prevalence of shoulder pain in wheelchair athletes as compared with nonathletic wheelchair users (39% vs. 66%), suggesting that athletic activity may be a protective factor in the wheelchair user, but further research is required to confirm this.

What Are the Inciting Events?

Inciting events are generally poorly reported across the available literature. However, it appears that contact/collision injuries and the mechanics of chair propulsion precipitate upper-extremity injuries in wheelchair athletes. Contact of the hand or wrist with the chair rim is the most commonly reported mode of injury, but many of these injuries do not require treatment and are not defined as injury in many studies. In addition, events involving high speed and collision potential (e.g., wheelchair basketball, wheelchair rugby, sledge hockey, Alpine skiing) are related to sustaining fracture in the lower extremities. Webborn et al. (2006) noted that in sledge hockey, being struck by the stick and collisions of sledges were common inciting events. Athletes with a visual impairment incur traumatic lower-limb injuries due to collision.

Injury Prevention

Curtis and Dillon (1985) proposed a variety of injury-prevention methods based on common patterns of injury that they documented in wheelchair athletes in one of the first studies to examine injuries in disability sports. Although other authors have cited these recommendations, to date no studies to confirm the effectiveness of these, or any other, measures have been performed. Moreover, while Paralympic sports generally use the standard protective equipment found in their able-bodied equivalents, this equipment is not always appropriate for the Paralympic population, and more research is needed to identify deficiencies in standard equipment in protecting Paralympic athletes and subsequent changes in injury rates if modifications are made. For example, based on analysis of lower-limb fractures in sledge hockey players in the 2002 winter Paralympic Games, Webborn et al. (2006) recommended, and had instituted, changes to both sledge heights and the standard ice hockey protective equipment for the lower extremities that was used by sledge hockey players. At the subsequent Paralympic Games in Torino in 2006 no lower-limb fractures were recorded in ice sledge hockey (Webborn 2007). Clearly, further studies need to be performed to confirm the efficacy of these interventions.

Further Research

This review of the data currently available on injuries in Paralympic sports has highlighted the difficulties and complexities of research in this area and the major deficiencies in our knowledge base due to methodologic limitations in the research. For example, many studies failed to provide a coherent definition of a reportable injury and often used self-report of symptom location rather than a medical diagnosis. It is important to standardize the definition of injury to ensure that results are comparable across studies (Finch 1997). Ferrara and colleagues (1990, 1992, 1996, 2000) have been consistent in their use of the definition of "any injury that caused an athlete to stop, limit or modify participation for one day or more." However, this does not identify whether the injury was severe enough to merit attention from a physician or therapist. A more appropriate definition would encompass this point – for example, "any injury requiring medical attention that caused an athlete to stop, limit, or modify participation."

The International Paralympic Committee (IPC) has committed to performing injury surveillance programs at Paralympic Games, which will provide insight into injuries occurring during elite competition. This initiative has been logistically easier to facilitate for the winter Paralympic Games because of the fewer number of sports to cover, making data collection more straightforward, and has allowed cross-referencing of clinical diagnoses with radiologic imaging, when it has been performed, to provide more accurate information than self-report questionnaires (Valuri et al. 2005). However, this approach does not capture injuries treated by the athletes' own medical team unless imaging has been requested through the polyclinic medical services.

In addition to the work of the IPC at the Paralympic Games, because of the unique nature of Paralympic sports, research needs to be both sport-specific and disability-specific to provide a better understanding of injury risk factors. Researchers should avoid combining data from different sports and different disability groups that can mask meaningful information by overgeneralization. Longitudinal studies in single sports can provide better data on exposure and the risk of injury for those sports, but this requires coordination and collaboration between competing nations to supply anonymous data on their athlete injuries based on the clinician diagnosis rather than self-report. Demographic information for any research should include, at a minimum, age, sex, sport, level of competition, and details of the individual's disability including classification. Currently, there are no studies that have adequately examined the relative risk of age on injury and few studies that have reported injury rates by sex. Other potentially important intrinsic risk factors in Paralympic sports that remain unexamined include malalignments, muscle imbalance, inflexibility, weakness, instability, and deficits in neuromuscular coordination, which are inherent in many Paralympic athletes by nature of their disability. For example, lower-limb amputee athletes have a built-in leg length discrepancy to allow the prosthetic limb to swing through more easily without catching but which may predispose them to hip or back injury. Athletes with spinal cord injury have inherent muscular weakness and impaired postural control, which may induce overuse injuries (Stankovits 2000). Burnham et al. (1993) found imbalance in the rotator-cuff muscles on isokinetic testing of wheelchair athletes with shoulder impingement, and Richter et al. (1991) reported a higher proportion of strains than other injuries in athletes with cerebral palsy, which may be related to alteration in tone, resulting in muscle imbalances, impaired coordination, and altered gait dynamics. Currently, there are no data on the association of these characteristics and injury in the relevant athlete populations.

Information on the mechanism of injury (derived from video analysis of television coverage of Paralympic events, when available) and whether it occurred during training, competition, or in a non–sport environment should be included to allow examination of the relationship between rates and types of injury during training and competition phases. For example, little epidemiologic work has been done on investigating propulsion technique as a risk factor for median-nerve neuropathy or other pathologies in wheelchair athletes. Nerve-conduction studies comparing elite wheelchair racers to the general wheelchair-using population have found that athletes had a similar or lower incidence of median nerve neuropathy (Boninger et al. 1996). Thus, sporting activity itself does not appear to be a risk factor, but technique or total workload may be. In addition, it has been suggested that quadriplegic athletes may be more susceptible to tendinitis at the wrist through the use of a "backhand" method of wheelchair propulsion, which allows those with higher-level lesions to engage their stronger muscles in force production (Burnham et al. 1991). The gloved back of the hand pushes the wheel rim, producing a forced passive flexion action followed by active wrist extension and forearm supination, but this remains an area for further research.

Although the evolution of Paralympic sports has brought about a greater degree of professionalism with regard to conditioning, coaching, and technological developments in sporting and protective equipment and injury prevention, little research has been conducted on the impact of these changes. For example, it is unknown whether better conditioning has reduced injury risk or whether exposure to more high-intensity training has increased it. Similarly lacking is research on the association between equipment and injury or the efficacy of purported injury-prevention regimens such as stretching. The protective impact of stretching remains an area of much conjecture in the sports medicine literature (Witvrouw et al. 2004; Andersen 2005; Hart 2005; Woods, Bishop & Jones 2007), although the suggestion of Curtis and Dillon (1985) that postactivity stretching may be beneficial in reducing shoulder pain has been widely reported. Even in spinal cord–injured patients, there is debate about whether there is a clinically beneficial effect from a typical stretching protocol applied by therapists (Harvey & Herbert 2002).

Data on time loss from training or competition is required as an indication of severity, as medically minor injury may have a significant impact on limiting performance. Although no catastrophic injuries are reported in the literature in Paralympic sports, these should be recorded in any evaluation. Finally, an effort should be made for long-term follow-up of injuries, as well as the physical benefits, that may evolve from participation in Paralympic sports to determine their impact on later life quality. For example, shoulder injury is common in wheelchair athletes, but the impact of these injuries in performing normal activities of daily living in the long term is unclear. However, Curtis et al. (1986) documented that spinal cord–injured athletes have fewer medical complications, with statistically significantly fewer physician visits, more hours of weekly employment, and more involvement in education, than spinal cord–injured nonathletes.

Unless researchers address these methodologic issues in future research, the injury risk of participation in Paralympic sports will continue to remain poorly understood. Only through well-designed longitudinal research can we identify risk factors for injury that will enable preventive measures to be used. While the IPC is directing injury surveillance at the Paralympic Games, international sports federations must prioritize and promote epidemiologic research in their respective sports. In due course, it may well become a legal requirement for sports organizations to undertake a risk assessment of their activities.

References

Allen, J.B. (2003) Sports injuries in disabled sailing. In: *4th European Conference on Sailing Sports Science and Sports Medicine and the 3rd Australian Sailing Science Conference* (Legg S.J. ed.), p. 58.

Andersen, J.C. (2005) Stretching before and after exercise: effect on muscle soreness and injury risk. *Journal of Athletic Training* **40**(3), 218–220.

Boninger, M.L., Robertson, R.N., Wolff, M. & Cooper, R.A. (1996) Upper limb nerve entrapments in elite wheelchair racers. *American Journal of Physical Medicine & Rehabilitation* **75**(3), 170–176.

Buckley, J.G. (1999) Spring kinematics of athletes with lower-limb amputations. *Archives of Physical Medicine and Rehabilitation* **80**, 501–508.

Burnham, R. & Higgins, R.S. (1994) Wheelchair basketball injuries. *Palaestra* **10**, 43–49.

Burnham, R., Newell, E. & Steadward, R.D. (1991) Sports medicine for the physically disabled: the Canadian team experience at the 1988 Seoul Paralympic Games. *Clinical Journal of Sports Medicine* **1**, 193–196.

Burnham, R.S., May, L., Nelson, E., Steadward, R. & Reid, D.C. (1993) Shoulder pain in wheelchair athletes: the role of muscle imbalance. *American Journal of Sports Medicine* **21**(2), 238–242.

Curtis, K.A. & Black, K. (1999) Shoulder pain in female wheelchair basketball players. *Journal of Orthopaedics and Sports Physical Therapy* **29**(4), 225–231.

Curtis, K.A. & Dillon, D.A. (1985) Survey of wheelchair athletic injuries: common patterns and prevention. *Paraplegia* **23**(3), 170–175.

Curtis, K.A., McClanahan, S., Hall, K.M., Dillon, D. & Brown, K.F. (1986) Health, vocational, and functional status in spinal cord injured athletes and nonathletes. *Archives of Physical Medicine and Rehabilitation* **67**(12), 862–865.

Ferrara, M.S. & Buckley, W.E. (1996) Athletes with Disabilities Injury Registry. *Adapted Physical Activity Quarterly* **13**(1), 50–60.

Ferrara, M.S., Buckley, W.E., McCann, B.C., Limbird, T.J., Powell, J.W. & Robl, R. (1992a) The injury experience of the competitive athlete with a disability: prevention implications. *Medicine and Science in Sports and Exercise* **24**(2), 184–188.

Ferrara, M.S., Buckley, W.E., Messner, D.G. & Benedict, J. (1992b) The injury experience and training history of the competitive skier with a disability. *American Journal of Sports Medicine* **20**(1), 55–60.

Ferrara, M.S. & Davis, R.W. (1990) Injuries to elite wheelchair athletes. *Paraplegia* **28**(5), 335–341.

Ferrara, M.S., Palutsis, G.R., Snouse, S. & Davis, R.W. (2000) A longitudinal study of injuries to athletes with disabilities. *International Journal of Sports Medicine* **21**(3), 221–224.

Ferrara, M.S. & Peterson, C.L. (2000) Injuries to athletes with disabilities: identifying injury patterns. *Sports Medicine* **30**(2), 137–143.

Finch, C.F. (1997) An overview of some definitional issues for sports injury surveillance. *Sports Medicine* **24**(3), 157–163.

Fullerton, H.D., Borckardt, J.J. & Alfano, A.P. (2003) Shoulder pain: a comparison of wheelchair athletes and

nonathletic wheelchair users. *Medicine and Science in Sports and Exercise* **35**(12), 1958–1961.
Hart, L. (2005) Effect of stretching on sport injury risk: a review. *Clinical Journal of Sports Medicine* **15**(2), 113.
Harvey, L.A & Herbert, R.D. (2002) Muscle stretching for treatment and prevention of contracture in people with spinal cord injury. *Spinal Cord* **40**(1), 1–9.
IPC. (2008) URL *www.paralympic.org* [accessed 22 May, 2009]
McCormack, D.A.R. & Reid, D.C. (1991) Injury profiles in wheelchair athletes: results of a retrospective survey. *Clinical Journal of Sports Medicine* **1**, 35–40.
McCormick, D.P. (1985) Injuries in handicapped Alpine skiers. *Physician and Sportsmedicine* **13,** 93–97.
Nyland, J., Snouse, S.L., Anderson, M., Kelly, T. & Sterling, J.C. (2000) Soft tissue injuries to USA paralympians at the 1996 summer games. *Archives of Physical Medicine & Rehabilitation* **81**(3), 368–373.
Reeser, J.C. (1999) Injury patterns among elite disabled standing volleyball players. *International Journal of Volleyball Research* **1**(1), 12–17.
Reynolds, J., Stirk, A., Thomas, A. & Geary, F. (1994) Paralympics-Barcelona 1992. *British Journal of Sports Medicine* **28**(1), 14–17.
Richter, K.J., Hyman, S.C., Adams-Mushett, C., Ellenberg, M.R. & Ferrara, M.S. (1991) Injuries to world class cerebral palsy athletes of the 1988 South Korea Paralympics. *Journal of Osteopathic Sports Medicine* **7,** 15–18.
Sobiecka, J. (2005) Injuries and ailments of the Polish participants of the 2000 Paralympic Games in Sydney. *Biology of Sport* **22**(4), 353–356.
Stankovits, S. (2000) The impact of seating and positioning on the development of repetitive strain injuries of the upper extremity in wheelchair athletes. *Work* **15**(1), 67–76.
Taylor, D. & Williams, T. (1995) Sports injuries in athletes with disabilities: wheelchair racing. *Paraplegia* **33**(5), 296–269.
Valuri, G., Stevenson, M., Finch, C., Hamer, P. & Elliott, B. (2005) The validity of a four week self-recall of sports injuries. *Injury Prevention* **11**(3), 135–137.
Webborn, A.D. (1999) Fifty years of competitive sport for athletes with disabilities: 1948–1998. *British Journal of Sports Medicine* **33**(2), 138.
Webborn, A.D. (2007) IPC Injury Survey Torino 2006. *The Paralympian* **11.**
Webborn, A.D. & Turner, H.M. (2000) The aetiology of shoulder pain in elite Paralympic wheelchair athletes – the shoulder or cervical spine? *5th Paralympic Scientific Congress. Sydney, Australia: International Paralympic Committee* **59.**
Webborn, N., Willick, S. & Reeser, J.C. (2006) Injuries among disabled athletes during the 2002 Winter Paralympic Games. *Medicine and Science in Sports and Exercise* **38**(5), 811–815.
Wilson, P.E. & Washington, R.L. (1993) Pediatric wheelchair athletics: sports injuries and prevention. *Paraplegia* **31**(5), 330–337.
Witvrouw, E., Mahieu, N., Danneels, L. & McNair, P. (2004) Stretching and injury prevention: an obscure relationship. *Sports Medicine* **34**(7), 443–449.
Woods, K., Bishop, P. & Jones, E. (2007) Warm-up and stretching in the prevention of muscular injury. *Sports Medicine* **37**(12), 1089–1099.
Yang, Y.S., Koontz, A.M., Triolo, R.J., Mercer, J.L. & Boninger, M.L. (2006) Surface electromyography activity of trunk muscles during wheelchair propulsion. *Clinical Biomechanics* **21**(10), 1032–1041.
Zimmer, M. (2007) Load for the musculoskeletal system by sports for disabled person. *Sports Orthopaedics and Traumatology* Volume 23, Issue 4, 24 January 2008.

PART 4

INJURY PREVENTION AND FURTHER RESEARCH

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Chapter 31

Injury Prevention in Sports

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Introduction

Similar to other types of injuries, sports injuries have often been viewed as accidents that occur as part of the game and thus, are not preventable (Chalmers 2002). In recent years, more research has focused on the prevention of injuries in sports to make participation safer for all players. Van Mechelen et al. (1992) and Finch (2006) have described models that translate the standard public health prevention model into the sports injury–prevention arena, moving from the description of the problem to the identification of injury causes and risk factors to the development and introduction of sports injury–prevention strategies. The prior chapters of this book have focused on individual Olympic sports, using this public health model in describing the scope of the injury problem, the associated risk factors, and the current prevention strategies. The purpose of this chapter is to take a broader perspective across all Olympic sports and to evaluate the current, evidence-based, effective injury-prevention strategies described in the literature as they apply to a variety of sports.

Although many of the prior sport-specific chapters describe injury-prevention strategies, we believe it is important to summarize injury-prevention findings that may apply to a wide variety of sports, rather than those that are sport-specific. Many of the Olympic sports have similar physical demands on the body such as running and cutting maneuvers for the lower extremities and hitting and throwing maneuvers for the upper extremities. These similarities in physical demands provide the rationale for evaluating injury-prevention strategies that might apply across different sports. In addition, we classify the specific injury-prevention measures as intrinsic and extrinsic. Intrinsic prevention measures involve factors that relate to the physical attributes of the athletes themselves. These strategies focus on conditioning the athlete by making him or her stronger and more able to withstand the demands of the sport, resulting in a decreased risk of sport-related injury. We evaluated studies using the specific interventions of strength training, stretching, balance training, educational videos, and interventions with multiple components. Because many sports require sport-specific equipment and rules, the extrinsic prevention measures we evaluated are factors that relate to equipment and rules. We evaluated studies of mouth guards, face shields, helmets, bracing, insoles and orthotics, breakaway bases, and the introduction of new sport-specific rules.

Intrinsic Injury-Prevention Strategies

In recent years, more research has focused on intrinsic injury-prevention strategies using rigorous methods as they apply to many of the Olympic sports. The intrinsic injury-prevention strategies that will be evaluated are strength training, stretching, balance training, educational video interventions, and multiple types of interventions.

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Strength Training

Several studies have evaluated the use of strength training in the prevention of hamstring strains. Askling et al. (2003) used a randomized, controlled trial in soccer players to evaluate a preseason hamstring-strengthening program and noted a 70% decrease in hamstring injuries. Another study of soccer players (Gabbe et al. 2006) found no effect of hamstring-strengthening interventions in a well-designed randomized, controlled trial, although the results of this study likely were affected by poor participation in the intervention sessions. Although both trials evaluating strength training used a randomized, controlled trial design, they were limited by reporting numbers of injuries rather than injury rates that account for each participant's athlete-exposure time. Although strength conditioning is a biologically plausible intervention for the prevention of strains of specific muscle groups, additional well-designed studies of this intervention are needed.

Stretching

Many athletes perform stretching exercises as part of their pre-exercise preparation for sport participation. Several randomized, controlled trials have evaluated the effect of static stretching in military recruits and found no effect on risk of injury (Pope et al. 1998; Pope et al. 2000). Other studies using a nonrandomized, controlled clinical trial design in football players (Cross & Worrell 1999) and military recruits (Hartig & Henderson 1999) found a decreased risk of injury, but these studies may have been affected by poor study methods, including nonrandomization, lack of a control group (Cross & Worrell 1999), and no adjustment for confounders or accounting for athlete-exposure time (Cross & Worrell 1999; Hartig & Henderson 1999). A systematic review pooling results from five controlled studies found no effect of stretching on sports injury (Thacker et al. 2004). In light of these findings, routine stretching exercises before initiation of sport activities are not a proven, effective method for reducing injury rates.

Balance Training

Balance training programs have been hypothesized to prevent sports injuries, especially those to the lower extremity and ankle. Studies have evaluated a variety of balance training programs during the sports season among athletes who participate in volleyball, handball, soccer, and basketball. The balance training programs have consisted of various components, including the use of a balance board or ankle disk, balance exercises such as maintaining a single-leg stance on a flat surface with eyes open and closed, and performing sports activities on one leg. The majority of studies noted a decreased risk of injuries overall and a decreased risk of ankle sprains (Wedderkopp et al. 1999, 2003; Verhagen et al. 2004; Emery et al. 2005; McGuine & Keene, 2006). Injuries were noted to be decreased by 50% to 85% with balance training (Verhagen et al. 2004; Emery et al. 2005; McGuine & Keene 2006). In contrast, Soderman et al. (2000) noted no effect of balance training on injuries among soccer players, but reported an increased risk of serious soccer injuries resulting in $\geqslant$30 days of participation lost among the intervention group. Verhagen et al. (2004) found a decreased risk of acute ankle injuries among volleyball players but an increased risk of overuse knee injuries associated with balance board training among athletes with a prior knee injury. The majority of these studies used rigorous methods for their study design and analysis. In light of these positive findings, balance training programs can be recommended as an effective prevention strategy for sports injuries.

Educational Video Interventions

Several studies have used video presentations to sport participants with the goal of decreasing the rate of injury. Two studies have focused on injury prevention for recreational skiers and ski resort employees. Jorgensen et al. (1998) evaluated the effect of an educational video on how to avoid injuries among skiers being transported by bus to ski resorts. Skiers were randomly assigned by busload to view or not to view the video. Skiing injury rates were decreased by 30% for those riding on the buses showing videos as compared with those on buses without the educational video. Another educational video intervention to prevent injury involved specific types of athletes viewing a video of an athlete at the time of an injury event. Following the viewing of the video, the athletes were instructed on using guided discovery to increase their awareness of injuries and their mechanism. An anterior cruciate ligament (ACL) injury-prevention program was developed using this guided discovery method for ski resort employees around the United States (Ettlinger et al. 1995). These investigators reported a 62% decreased risk of ACL injuries among ski resort employees who participated in the program as compared with those who did not participate, although these results must be viewed with caution because of the nonrandomized design, with the potential for confounding and the lack of adjustment for exposure time for each subject. Arnason et al. (2005) used a similar type of video training in a randomized, controlled trial for adult male soccer players and found no effect on injury rates. Although video analysis by athletes may raise awareness of the mechanisms of injury, it is unclear whether this intervention method is effective in decreasing the risk of sports injury. Further studies are needed.

Multiple Interventions

Although the studies discussed above have used a single intervention approach to preventing injuries, many studies have used multiple interventions that combine two or more sports injury–prevention activities in a single trial. Several rigorously designed, randomized, controlled studies compared warm-up activities and balance training on a wobble board to the usual training in youth handball (Olsen et al. 2005) and basketball (Emery et al. 2007) players. The handball players also had strength training. These studies found a 30% to 50% decreased risk of acute injuries among the intervention group compared to the control group. Van Mechelen et al. (1993) and Ekstrand et al. (1983) also performed randomized, controlled studies to evaluate warm-up, cool-down, and either stretching (van Mechelen et al. 1993) or ankle taping (Ekstrand et al. 1983) among soccer (Ekstrand et al. 1983) and recreational runners (van Mechelen et al. 1993). van Mechelen et al. (1993) noted no effect of the intervention, while Ekstrand et al. (1983) found a 75% decreased risk of injuries. Another randomized, controlled trial (Heidt et al. 2000) in female youth soccer players used the Frappier Acceleration Training Program, which incorporates cardiovascular conditioning, plyometrics, and strength and flexibility training into the intervention group. Those in the intervention group had a decreased risk of injury as compared with the control group.

Numerous nonrandomized, controlled trials using multiple interventions have been performed, with many showing a decrease in injuries in the intervention group. Several of the nonrandomized trials have focused on jumping and landing skills as well as proprioceptive training (Caraffa et al. 1996; Hewett et al. 1999; Mandelbaum et al. 2005; Petersen et al. 2005; Scase et al. 2006). These studies evaluated soccer, basketball, and volleyball players and noted a 28% decrease in any injuries (Scase et al. 2006) and a 70% to 80% decrease in knee injuries (Caraffa et al. 1996; Hewett et al. 1999; Mandelbaum et al. 2005). A study of female handball players focusing on jumping and landing skills along with use of a balance training component found no effect on the risk of injury (Petersen et al. 2005). Other studies of multiple interventions have evaluated combinations of warm-up and cool-down exercises as well as strengthening and stretching exercises among soccer (Junge et al. 2002) and rugby players (Brooks et al. 2006) and long distance runners (Jakobsen et al. 1994). All have noted a decreased risk of injury with these interventions. Findings from these nonrandomized trials should be viewed with caution because of the potential for selection bias of the study subjects and the possibility of confounding as an explanation for the protective effect. In conclusion, the use of multiple interventions to prevent sports injuries appears promising and should be investigated further. One limitation of intervention trials that use multiple interventions in a trial group is that it is difficult to characterize the contribution of each aspect of the intervention to the decrease in injury. Future studies should consider the possibility of comparing several intervention groups to the control arm to separate the effects of each type of intervention.

Extrinsic Injury-Prevention Strategies

Some of the first sports injury–prevention strategies have focused on extrinsic strategies, mainly protective equipment. The extrinsic injury prevention strategies that will be evaluated are mouth guards, face shields, helmets, bracing and orthosis use, insoles and footwear, breakaway bases, and sporting rules.

Mouth Guards

The effectiveness of mouth guards has been studied for a number of years among athletes in several different sports, including rugby, basketball, American football, and hockey. Mouth guards, regardless of the type of device, have been consistently shown to decrease the risk of orofacial injuries such as dental, mouth, and jaw injuries. One study (Finch et al. 2005) using rigorous methods, including a randomized, controlled design with an intention-to-treat analysis documented a 44% decreased risk of head and orofacial injuries among users of mouth guards. A meta-analysis (Knapik et al. 2007) of 13 studies evaluating the effects of mouth guards documented a pooled effect of an 86% increased risk of orofacial injuries among nonusers of mouth guards. Mouth guards in these studies were used by athletes participating in American football, basketball, and Australian football. In addition to the prevention of orofacial injuries, some studies (Labella et al. 2002; Barbic et al. 2005; Mihalik et al. 2007) have evaluated the association between mouthguard use and the risk of concussion and neuropsychological symptoms following concussion. None of these studies found a protective effect of mouth guards on the risk of concussion.

Face Shields

Face shields are another extrinsic type of injury-prevention strategy that has been evaluated for use in sports with a high risk for facial injury, such as ice hockey and baseball. Although no randomized, controlled trials have evaluated face shields, several cohort studies (Benson et al. 1999; Stuart et al. 2002; Woods et al. 2007) have shown a protective effect of face shields on the risk of injuries, including facial lacerations, facial fractures, dental injuries, and head injuries. Stuart et al. (2002) documented a dose–response effect with the amount of facial protection provided among ice hockey players, with the risk of injury decreased by 54% with use of a partial face shield and injury risk decreased by 85% with use of a full face shield. Benson et al. (1999) also noted that half face shields were associated with a nearly 10-fold increased risk of dental injuries as compared with full face shields among ice hockey players. In a study of youth baseball players, Marshall et al. (2003) using an ecologic study design reported that the use of face guards was associated with a 35% decreased risk of facial injuries. Although these results appear promising, all these studies were observational and had methodologic limitations, including lack of control for potential confounders (Benson et al. 1999; Stuart et al. 2002; Woods et al. 2007) and lack of account for clustering by team (Benson et al. 1999; Stuart et al. 2002; Woods et al. 2007).

Helmets

Use of helmets is applicable to a variety of Olympic sports, including baseball, ice hockey, bicycling, equestrian, bobsleigh, skiing, and snowboarding. Similar to the evaluation of face shields, no randomized trials have been performed to evaluate the effect of helmet use on head injuries. Using a case–control study design, numerous studies of bicycle helmets have shown that they are effective in decreasing the risk of head injuries. A Cochrane review (Thompson et al. 1999) of five case–control studies found that helmet use decreased the risk of head injuries by 69% (odds ratio [OR], 0.31; 95% confidence interval [CI], 0.2–0.48) and decreased the risk of facial injuries by 65% (OR, 0.35; 95% CI, 0.24–0.50). More recent studies have evaluated the effectiveness of helmets for skiers and snowboarders in the prevention of head, face, and neck injuries. These studies also used a case–control design and all noted a protective effect of helmet use. Macnab et al. (2002) reported a 77% increased risk of head, neck, or face injury with failure to wear a helmet during skiing or snowboarding, although this study adjusted only for type of activity but no other confounding factors. Several other case–control studies (Hagel et al. 2005b; Sulheim et al. 2006; Mueller et al. 2008) have found a 15% to 60% decrease in risk of a head injury, using more rigorous study methods that have adjusted for confounding. The effect of helmet use on the risk of head injuries in other sports such as baseball, softball, and ice hockey has not been evaluated, although its use is likely effective.

Bracing and Orthosis Use

Another extrinsic injury-prevention measure that has been evaluated is the use of joint bracing or support. Several individual studies along with a meta-analysis have evaluated the effects of orthoses and taping on the risk of ankle sprains. Using a randomized, controlled trial, Surve et al. (1994) found a decreased risk of recurrent ankle sprain among soccer players using a sport-stirrup orthosis. A meta-analysis (Handoll et al. 2007) of five studies of ankle orthoses among basketball and soccer athletes noted an overall 47% decreased risk of ankle sprain. A study of high-school athletes by Yang et al. (2005) evaluated discretionary protective equipment and found a 56% decreased risk of knee injuries with the use of knee pads and a 61% increased risk of knee injuries with the use of a knee brace, although some of these results may be confounded by reasons for use of this equipment.

In addition to lower-extremity bracing, some studies of snowboarders have evaluated the effectiveness of wrist protectors on the risk of wrist and upper-extremity injury. Two randomized, controlled trials (Machold et al. 2002; Ronning et al. 2001) and one case–control study (Hagel et al. 2005a) have shown a 72% to 87% decreased risk of wrist injuries, including wrist fractures and sprains, among snowboarders who used wrist protectors. The effect of wrist protectors on the risk of shoulder or upper-arm injuries has also been evaluated. Machold et al. (2002) noted a nonsignificant decreased risk of shoulder injuries among the group who used wrist protectors, whereas Hagel et al. (2005a) noted a nonsignificant increased risk of injuries between the elbow and the shoulder in a case–control study. Although wrist protectors appear to decrease wrist injuries, additional studies are needed to determine effects on the risk of other upper-extremity injuries before wrist protectors can be recommended for injury prevention among snowboarders.

Insoles and Footwear

Orthotics and shoe insoles have been used as potential prevention measures for overuse injuries and stress fractures. The majority of studies of orthotics and insoles have been performed in military populations, with conflicting results. Investigators (Gardner et al. 1988; Withnall et al. 2006) have evaluated polymer and polyurethane foam insoles in military populations and noted no effect on lower-extremity stress fractures or any type of lower-extremity injury. Milgrom et al. (1985) noted a 50% decreased risk of stress fractures with the use of orthotics. Schwellnus et al. (1990) evaluated the effect of neoprene insoles using a randomized, controlled trial and found a 34% decreased risk of overuse injuries among those in the insole group. Several studies (Andrish et al. 1974; Bensel & Kaplan 1986; Schwellnus et al. 1990) have evaluated the effect of insoles on the development of shin splints, with only one of the studies (Schwellnus et al. 1990) reporting a 59% decrease in shin splints. None of the studies of orthotics and insoles have evaluated their effectiveness in athletes participating in sports with a high risk of lower-extremity injuries and stress fractures such as basketball, soccer, volleyball, and handball. In addition to evaluations of orthotics and insoles, only one study has evaluated the type of shoe as a sports injury–prevention strategy. Barrett et al. (1993) evaluated high-top versus low-top shoes for the prevention of ankle sprains in basketball players and noted no statistically significant effect, although this study was limited by relatively few ankle sprains among the players.

Breakaway Bases

Bases in softball and baseball are another type of extrinsic injury-prevention strategy that has been evaluated. Unlike standard bases, breakaway bases will release from their anchors at a lower amount of force as compared with standard bases. Janda et al. (1988) compared numbers of softball sliding injuries that occurred on fields with standard bases with those that occurred on fields with breakaway bases and found a 96% decreased risk of sliding injuries with breakaway bases. Sendre et al. (1994) also evaluated the effect of breakaway bases on the rate of any type of injury per athlete-exposure time among softball and baseball players and found a 97% decreased risk of sliding-related injuries among recreational and college softball players who played on fields with breakaway bases. Although breakaway bases appear to be an effective strategy for the prevention of softball sliding injuries, these studies were not randomized and did not account for confounding factors.

Sporting Rules

All sports have specific rules for the purpose of regulating the game or sporting activity. Some sporting rules have been developed for the specific purpose of decreasing the risk of injury. Relatively few studies have evaluated the effect of rules or rule changes on the risk of sports injuries, and the existing studies have been limited to a few sports, such as ice hockey and tae kwon do. Macpherson et al. (2006) and Brunelle et al. (2006) conducted studies to evaluate the introduction of body-checking rules in Canadian youth ice hockey on the risk of injuries. Macpherson et al. (2006) reported a 45% decreased risk of checking-related injuries as compared with all other injuries when the body checking was prohibited, although this study was limited by a lack of accounting for athlete-exposure time and other confounding factors and restricting injury ascertainment to selected pediatric emergency departments in the study area. In contrast, Brunelle et al. (2006) noted no effect of the institution of a fair-play program on injury rates among youth hockey players, although this study was limited by a poor response rate and a lack of accounting for athlete-exposure time and other confounding factors. The only study of tae kwon do (Burke et al. 2003) evaluated the introduction of a light-contact rule on the risk of injury, comparing injury rates after the introduction of the rule to injury rates from prior studies. Although they reported a lower injury rate as compared with historical injury rates, the results must be viewed with caution because no information was provided on the study populations and injury surveillance systems used in the historical studies. Changes in sporting rules may have an impact on reducing the rate of injury in a variety of sports; however, current evidence to support rule changes is very limited.

Conclusion

Although sports-injury epidemiology is a relatively new field, investigations of injury-prevention strategies have identified several effective measures to decrease the risk of injuries. Factors that are intrinsic to the athlete, such as different aspects of conditioning, appear to be promising areas for the prevention of sports injuries. Balance training appears to decrease the risk of lower-extremity injuries, especially ankle injuries. Strength training appears promising, but more rigorously designed trials are needed. Multiple interventions using warm-up and balance training are effective. In addition to intrinsic types of interventions, much research has focused on the use of protective equipment. The use of breakaway bases, mouth guards, helmets, and face shields, along with bracing of specific joints, have resulted in a decrease in sports injuries. Some of this protective equipment use has been mandated in youth sports but still needs to be incorporated into adult and Olympic sports.

This evaluation of effective areas of injury prevention has highlighted additional areas that need further investigation. Upper-extremity injuries occur in many of the sports discussed in this book, and the effect of conditioning on the prevention of upper-extremity injury is needed. Another area lacking in sports injury–prevention research is interventions for overuse injuries. Lastly, the methods for implementing injury prevention strategies are important (Finch et al. 2006). Understanding the context and the culture of the individual sport is essential for effectively implementing a prevention strategy with regard to the recruitment of subjects into the study, the acceptability of randomizing subjects or teams into intervention and control groups, and the level of compliance with the intervention.

In reviewing the injury-prevention sections of each sport-specific chapter, progress has been made in the prevention of injuries using intrinsic interventions in specific team sports such as soccer, volleyball, handball, and basketball. Progress has also been made in the use of extrinsic or equipment interventions in the sports of skiing, snowboarding, ice hockey, and baseball. Despite effective prevention strategies in these selected sports, the majority of the sport-specific chapters found no injury-prevention studies. Much research is needed to identify modifiable risk factors that will lead to the development and rigorous evaluation of new interventions. The application of epidemiologic methods to this ongoing investigation will provide the definitive answers to the questions of how to effectively prevent sports injuries.

References

Andrish, J.T., Bergfeld, J.A. & Walheim, J. (1974) A prospective study on the management of shin splints. *Journal of Bone and Joint Surgery, American* **56**, 1697–1700.

Arnason, A., Engebretsen, L. & Bahr, R. (2005) No effect of a video-based awareness program on the rate of soccer injuries. *American Journal of Sports Medicine* **33**, 77–84.

Askling, C., Karlsson, J. & Thorstensson, A. (2003) Hamstring injury occurrence in elite soccer players after preseason strength training with eccentric overload. *Scandinavian Journal of Medicine and Science in Sports* **13**, 244–250.

Barbic, D., Pater, J. & Brison, R.J. (2005) Comparison of mouth guard designs and concussion prevention in contact sports: a multicenter randomized controlled trial, *Clinical Journal of Sport Medicine* **15**, 294–298.

Barrett, J.R., Tanji, J.L., Drake, C., Fuller, D., Kawasaki, R.I. & Fenton, R.M. (1993) High- versus low-top shoes for the prevention of ankle sprains in basketball players: a prospective randomized study. *American Journal of Sports Medicine* **21**, 582–585.

Bensel C.K. & Kaplan D.B. (1986) Wear test of boot inserts: memorandum for the record. U.S. Army Natick Research and Development Laboratories, Natick, MA, December, 1–8.

Benson, B.W., Mohtadi, N.G., Rose, M.S. & Meeuwisse, W.H. (1999) Head and neck injuries among ice hockey players wearing full face shields vs half face shields, *Journal of the American Medical Association* **282**, 2328–2332.

Brooks, J.H., Fuller, C.W., Kemp, S.P. & Reddin, D.B. (2006) Incidence, risk, and prevention of hamstring muscle injuries in professional rugby union. *American Journal of Sports Medicine* **34**, 1297–1306.

Brunelle, J.P., Goulet, C. & Arguin, H. (2005) Promoting respect for the rules and injury prevention in ice hockey: evaluation of the fair-play program. *Journal of Science and Medicine in Sport Sports Medicine Australia*. **8**, 294–304.

Burke, D.T., Barfoot, K., Bryant, S., Schneider, J.C., Kim, H.J. & Levin, G. (2003) Effect of implementation of safety measures in tae kwon do competition. *British Journal of Sports Medicine* **37**, 401–404.

Caraffa, A., Cerulli, G., Projetti, M., Aisa, G. & Rizzo, A. (1996), Prevention of anterior cruciate ligament injuries in soccer: a prospective controlled study of proprioceptive training. *Knee Surgery, Sports Traumatology, Arthroscopy* **4**, 19–21.

Chalmers, D.J. (2002), Injury prevention in sport: not yet part of the game? *Injury Prevention* **8**, Suppl 4, IV22–IV25.

Cross, K.M. & Worrell, T.W. (1999) Effects of a static stretching program on the incidence of lower extremity musculotendinous strains. *Journal of Athletic Training*, **34**, 11–14.

Ekstrand, J., Gillquist, J. & Liljedahl, S.O. (1983) Prevention of soccer injuries: supervision by doctor and physiotherapist. *American Journal of Sports Medicine* **11**, 116–120.

Emery, C.A., Cassidy, J.D., Klassen, T.P., Rosychuk, R.J. & Rowe, B.H. (2005) Effectiveness of a home-based balance-training program in reducing sports-related injuries among healthy adolescents: a cluster randomized controlled trial.*Canadian Medical Association Journal* **172**, 749–754.

Emery, C.A., Rose, M.S., McAllister, J.R. & Meeuwisse, W.H. (2007) A prevention strategy to reduce the incidence of injury in high school basketball: a cluster randomized controlled trial. *Clinical Journal of Sport Medicine* **17**, 17–24.

Ettlinger, C.F., Johnson, R.J. & Shealy, J.E. (1995) A method to help reduce the risk of serious knee sprains incurred in alpine skiing. *American Journal of Sports Medicine*, **23**, 531–537.

Finch, C. (2006) A new framework for research leading to sports injury prevention. *Journal of Science and Medicine in Sport* **9**, 3–10.

Finch, C., Braham, R., McIntosh, A., McCrory, P. & Wolfe, R. (2005) Should football players wear custom fitted mouthguards? Results from a group randomised controlled trial. *Injury Prevention* **11**, 242–246.

Gabbe, B.J., Branson, R. & Bennell, K.L. (2006) A pilot randomised controlled trial of eccentric exercise to prevent hamstring injuries in community-level Australian Football. *Journal of Science and Medicine in Sport* **9**, 103–109.

Gardner, L.I., Jr., Dziados, J.E., Jones, B.H., Brundage, J.F., Harris, J.M., Sullivan, R. & Gill, P. (1988) Prevention of lower extremity stress fractures: a controlled trial of a shock absorbent insole. *American Journal of Public Health* **78**, 1563–1567.

Hagel, B., Pless, I.B. & Goulet, C. (2005a) The effect of wrist guard use on upper-extremity injuries in snowboarders. *American Journal of Epidemiology* **162**, 149–156.

Hagel, B.E., Pless, I.B., Goulet, C., Platt, R.W. & Robitaille, Y. (2005b) Effectiveness of helmets in skiers and snowboarders: case-control and case crossover study. *British Medical Journal (Clinical Research Edition)* **330**, 281–286.

Handoll, H.H., Rowe, B.H., Quinn, K.M., de Bie, R. (2001) Interventions for preventing ankle ligament injuries. *Cochrane Database System Review* **3,** CD000018.

Hartig, D.E. & Henderson, J.M. (1999) Increasing hamstring flexibility decreases lower extremity overuse injuries in military basic trainees. *American Journal of Sports Medicine* **27**, 173–176.

Heidt, R.S., Jr., Sweeterman, L.M., Carlonas, R.L., Traub, J.A. & Tekulve, F.X. (2000) Avoidance of soccer injuries with preseason conditioning. *American Journal of Sports Medicine* **28**, 659–662.

Hewett, T.E., Lindenfeld, T.N., Riccobene, J.V. & Noyes, F.R. (1999) The effect of neuromuscular training on the incidence of knee injury in female athletes: a prospective study. *American Journal of Sports Medicine* **27**, 699–706.

Jakobsen, B.W., Kroner, K., Schmidt, S.A. & Kjeldsen, A. (1994) Prevention of injuries in long-distance runners, *Knee Surgery, Sports Traumatology, Arthroscopy* **2**, 245–249.

Janda, D.H., Wojtys, E.M., Hankin, F.M. & Benedict, M.E. (1988) Softball sliding injuries: a prospective study comparing standard and modified bases. *Journal of the American Medical Association* **259**, 1848–1850.

Jorgensen, U., Fredensborg, T., Haraszuk, J.P. & Crone, K.L. (1998) Reduction of injuries in downhill skiing by use of an instructional ski-video: a prospective randomised intervention study. *Knee Surgery, Sports Traumatology, Arthroscopy* **6**, 194–200.

Junge, A., Rosch, D., Peterson, L., Graf-Baumann, T. & Dvorak, J. (2002) Prevention of soccer injuries: a prospective intervention study in youth amateur players. *American Journal of Sports Medicine* **30**, 652–659.

Knapik, J.J., Marshall, S.W., Lee, R.B., Darakjy, S.S., Jones, S.B., Mitchener, T.A., delaCruz, G.G. & Jones, B.H. (2007) Mouthguards in sport activities: history, physical properties and injury prevention effectiveness. *Sports Medicine* **37**, 117–144.

Labella, C.R., Smith, B.W. & Sigurdsson, A. (2002) Effect of mouthguards on dental injuries and concussions in college basketball. *Medicine and Science in sports and Exercise* **34**, 41–44.

Machold, W., Kwasny, O., Eisenhardt, P., Kolonja, A., Bauer, E., Lehr, S., Mayr, W. & Fuchs, M. (2002) Reduction of severe wrist injuries in snowboarding by an optimized wrist protection device: a prospective randomized trial. *Journal of Trauma* **52**, 517–520.

Macnab, A.J., Smith, T., Gagnon, F.A. & Macnab, M. (2002) Effect of helmet wear on the incidence of head/face and cervical spine injuries in young skiers and snowboarders. *Injury Prevention* **8**, 324–327.

Macpherson, A., Rothman, L. & Howard, A. (2006) Body-checking rules and childhood injuries in ice hockey. *Pediatrics* **117**, e143–e147.

Mandelbaum, B.R., Silvers, H.J., Watanabe, D.S., Knarr, J.F., Thomas, S.D., Griffin, L.Y., Kirkendall, D.T. & Garrett, W., Jr. (2005) Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: 2-year follow-up., *American Journal of Sports Medicine* **33**, 1003–1010.

Marshall, S.W., Mueller, F.O., Kirby, D.P. & Yang, J. (2003) Evaluation of safety balls and faceguards for prevention of injuries in youth baseball. *Journal of the American Medical Association* **289**, 568–574.

McGuine, T.A. & Keene, J.S. (2006) The effect of a balance training program on the risk of ankle sprains in high school athletes. *American Journal of Sports Medicine* **34**, 1103–1111.

Mihalik, J.P., McCaffrey, M.A., Rivera, E.M., Pardini, J.E., Guskiewicz, K.M., Collins, M.W. & Lovell, M.R. (2007) Effectiveness of mouthguards in reducing neurocognitive deficits following sports-related cerebral concussion. *Dental Traumatology* **23**, 14–20.

Milgrom, C., Giladi, M., Kashtan, H., Simkin, A., Chisin, R., Margulies, J., Steinberg, R., Aharonson, Z. & Stein, M. (1985) A prospective study of the effect of a shock-absorbing orthotic device on the incidence of stress fractures in military recruits. *Foot and Ankle* **6**, 101–104.

Mueller, B.A., Cummings, P., Rivara, F.P., Brooks, M.A. & Terasaki, R.D. (2008) Injuries of the head, face, and neck in relation to ski helmet use. *Epidemiology* **19**, 270–276.

Olsen, O.E., Myklebust, G., Engebretsen, L., Holme, I. & Bahr, R. (2005) Exercises to prevent lower limb injuries in youth sports: cluster randomised controlled trial. *British Medical Journal (Clinical Research Edition)* **330**, 449.

Petersen, W., Braun, C., Bock, W., Schmidt, K., Weimann, A., Drescher, W., Eiling, E., Stange, R., Fuchs, T., Hedderich, J. & Zantop, T. (2005) A controlled prospective case control study of a prevention training program in female team handball players: the German experience. *Archives of Orthopaedic and Trauma Surgery* **125**, 614–621.

Pope, R., Herbert, R. & Kirwan, J. (1998) Effects of ankle dorsiflexion range and pre-exercise calf muscle stretching on injury risk in Army recruits. *Australian Journal of Physiotherapy* **44**, 165–172.

Pope, R.P., Herbert, R.D., Kirwan, J.D. & Graham, B.J. (2000) A randomized trial of preexercise stretching for prevention of lower-limb injury. *Medicine and Science in Sports and Exercise* **32**, 271–277.

Ronning, R., Ronning, I., Gerner, T. & Engebretsen, L. (2001) The efficacy of wrist protectors in preventing snowboarding injuries. *American Journal of Sports Medicine* **29**, 581–585.

Scase, E., Cook, J., Makdissi, M., Gabbe, B. & Shuck, L. (2006) Teaching landing skills in elite junior Australian football: evaluation of an injury prevention strategy. *British Journal of Sports Medicine* **40**, 834–838.

Schwellnus, M.P., Jordaan, G. & Noakes, T.D. (1990) Prevention of common overuse injuries by the use of shock absorbing insoles: a prospective study. *American Journal of Sports Medicine* **18**, 636–641.

Sendre, R.A., Keating, T.M., Hornak, J.E. & Newitt, P.A. (1994) Use of the Hollywood Impact Base and standard stationary base to reduce sliding and base-running injuries in baseball and softball. *American Journal of Sports Medicine* **22**, 450–453.

Soderman, K., Werner, S., Pietila, T., Engstrom, B. & Alfredson, H. (2000) Balance board training: prevention of traumatic injuries of the lower extremities in female soccer players? A prospective randomized intervention study. *Knee Surgery, Sports Traumatology, Arthroscopy* **8**, 356–363.

Stuart, M.J., Smith, A.M., Malo-Ortiguera, S.A., Fischer, T.L. & Larson, D.R. (2002) A comparison of facial protection and the incidence of head, neck, and facial injuries in

Junior A hockey players: a function of individual playing time.*American Journal of Sports Medicine* **30**, 39–44.
Sulheim, S., Holme, I., Ekeland, A. & Bahr, R. (2006) Helmet use and risk of head injuries in alpine skiers and snowboarders. *Journal of the American Medical Association* **295**, 919–924.
Surve, I., Schwellnus, M.P., Noakes, T. & Lombard, C. (1994) A fivefold reduction in the incidence of recurrent ankle sprains in soccer players using the Sport-Stirrup orthosis. *American Journal of Sports Medicine* **22**, 601–606.
Thacker, S.B., Gilchrist, J., Stroup, D.F. & Kimsey, C.D., Jr. (2004) The impact of stretching on sports injury risk: a systematic review of the literature. *Medicine and Science in Sports and Exercise* **36**, 371–378.
Thompson, D., Rivara, F. & Thompson, R. (1999) Helmets for preventing head and facial injuries in bicyclists. *Cochrane Database of Systematic Reviews* **4** URL http://www.mrw.interscience.wiley.com/cochrane/clsysrev/articles/CD001855/pdf_standard_fs.html [accessed May 27, 2008]
van Mechelen, W., Hlobil, H. & Kemper, H.C. (1992) Incidence, severity, aetiology and prevention of sports injuries: a review of concepts. *Sports Medicine* **14**, 82–99.
van Mechelen, W., Hlobil, H., Kemper, H.C., Voorn, W.J. & de Jongh, H.R. (1993) Prevention of running injuries by warm-up, cool-down, and stretching exercises.*American Journal of Sports Medicine* **21**, 711–719.
Verhagen, E., van der Beek, A., Twisk, J., Bouter, L., Bahr, R. & van Mechelen, W. (2004) The effect of a proprioceptive balance board training program for the prevention of ankle sprains: a prospective controlled trial. *American Journal of Sports Medicine* **32**, 1385–1393.
Wedderkopp, N., Kaltoft, M., Holm, R. & Froberg, K. (2003) Comparison of two intervention programmes in young female players in European handball—with and without ankle disc. *Scandinavian Journal of Medicine and Science in Sports* **13**, 371–375.
Wedderkopp, N., Kaltoft, M., Lundgaard, B., Rosendahl, M. & Froberg, K. (1999) Prevention of injuries in young female players in European team handball: a prospective intervention study. *Scandinavian Journal of Medicine and Science in Sports* **9**, 41–47.
Withnall, R., Eastaugh, J. & Freemantle, N. (2006) Do shock absorbing insoles in recruits undertaking high levels of physical activity reduce lower limb injury? A randomized controlled trial. *Journal of the Royal Society of Medicine* **99**, 32–37.
Woods, S.E., Zabat, E., Daggy, M., Diehl, J., Engel, A. & Okragly, R. (2007) Face protection in recreational hockey players. *Family Medicine* **39**, 473–476.
Yang, J., Marshall, S.W., Bowling, J.M., Runyan, C.W., Mueller, F.O. & Lewis, M.A. (2005) Use of discretionary protective equipment and rate of lower extremity injury in high school athletes. *American Journal of Epidemiology* **161**, 511–519.

Chapter 32

Conclusions and Further Research

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Of all of the challenges inherent in sports competition, sustaining an injury is one of the most problematic. It is a truism that even the most gifted and well-prepared athlete cannot perform to full potential if injured. As in all previous Olympic Games, the 2008 Beijing Games provided ample evidence of this, ranging from athletes who qualified but had to withdraw because injury, including defending Olympic gold medalist Paul Hamm of the U.S. gymnastics team (broken hand) and Ana Ivanovic of Serbia, the top seed in the women's tennis competition (thumb injury), to those who competed despite injury, including the great Chinese basketball player Yao Ming, who was hampered by a recurrent ankle injury and Roman Sebrle from the Czech Republic, the defending world and Olympic champion in the decathlon (thigh injury) ("Olympic injuries" 2008). Even injuries considered relatively minor from a medical perspective, such as blisters and strains, can have a significant impact on performance. At the other end of the spectrum, competing in many sports entails the risk of catastrophic or fatal injury. In the 2006 Asian Games in Doha, Qatar, a South Korean rider was killed during the equestrian cross-country event ("S. Korean rider" 2006).

Given the life-changing impact injury can have in sports (personal, social, financial, psychological, political, medical), the current paucity of well-designed epidemiologic studies in the majority of Olympic sports is disturbing. In reviewing the extant literature on injuries in sports for this book, we found surprisingly little data-based research in some sports with long Olympic histories or worldwide popularity or both. For example, archery and modern pentathlon are included, but the quantity and quality of published work the authors had available to evaluate was minimal. For three sports from the Summer Games (canoe/kayak, shooting, table tennis) and five sports/events from the Winter Games (biathlon, bobsleigh, skiing [cross-country, freestyle, Nordic combined, jumping], curling, luge), we were unable to find sufficient research to support their inclusion.

It has been argued that in addition to the practical value of minimizing or eliminating injuries to maximize performance, sports organizations, such as the International Olympic Committee (IOC) and the international federations (IFs) which control specific sports, have an ethical obligation to ensure the health and well-being of competitors under their authority (Harmer 1991). This ethical imperative is valid irrespective of the demonstrated, or perceived, risk involved in a particular sport but is most salient for high-risk activities. To date, few organizations have met this obligation by supporting research on the epidemiology of injury in sport. Currently, the National Collegiate Athletic Association (NCAA) Injury Surveillance System (ISS) in the United States (www.ncaa.org/iss) is the most comprehensive model of this type. A special issue of the *Journal of Athletic Training* [2007, **42**(2)] was devoted to reports on 16 years of NCAA ISS epidemiologic data involving

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11 intercollegiate sports, of which 9 are Olympic sports. Although the NCAA population of interest is narrow, the quality and scope of the descriptive data are exceptional because the system involves all of the important features needed to capture unambiguous and consistent information, including standardized definitions of reportable injuries, qualified injury evaluators and data recorders, a consistent measure of exposure, large sample sizes, and long-term data collection. These characteristics are among those most consistently remarked upon by authors in this book as lacking in the research in the sports they examined.

The fact that the IOC Medical Commission has been slow to use its prestige or resources to address the significant gaps in our knowledge related to the epidemiology of injury in Olympic sports is indicative of the complacency about injury found in many sports organizations. Despite the self-evident value of this line of research, and express calls to pursue such work, both from a public health and sports-specific standpoint (e.g., Chalmers et al. 1999), no significant attempt was undertaken by the IOC until a study of injuries in team events during the 2004 Olympic Games in Athens (Junge et al. 2006). Although this step was encouraging, considerably greater efforts are needed. A letter dated June 6, 2008, from the IOC Medical and Scientific Department to the medical directors of IFs and National Olympic Committees (NOCs) indicated that "the IOC is granting increasing importance to the protection of athletes' health" and would be extending its study of injury prevention in the 2008 Beijing Games to include all sports. The framework used in Athens was modified and expanded to accommodate individual and dual sports (Junge et al. 2008). Initial results for all sports combined were released by the IOC in November, 2008. Plans for the publication of sport-specific data have not been finalized.

Although the IOC plan is an important development in establishing a sound scientific approach to understanding the nature, scope, and determinants of injury in Olympic sports, it must not be construed as an end in itself. Despite the argument that "the incidence and characteristics of injuries in different sports can best be compared within one study" (Junge et al. 2006, p. 566), the restrictions on the number of competing athletes and the quadrennial staging of the Games necessarily limits the sample sizes and concurrent exposure opportunities. These limitations make the data susceptible to atypical fluctuations in the incidence of injury and place the findings in jeopardy. Combined data from longitudinal study of world cups and world championships of specific sports are more likely to yield meaningful results for elite athletes, particularly for subtle risk factors. Thus, while injury data from large multiple-sports events such as the Olympic Games are essential for medical-coverage planning, they are less valuable for understanding risk and risk factors in each sport involved, offer little opportunity to ascertain the efficacy of injury-prevention measures, have no capacity for follow-up, and are restricted to one athlete population (i.e., elite).

Further Research

Despite the usable epidemiologic information that has been gathered in some sports, it is evident from the commentary and suggestions outlined in the "Further Research" sections of each chapter that much needs to be improved in every sport. Most sports lack even good quality descriptive data, the fundamental building blocks of epidemiology, without which the capacity to conduct meaningful analytical studies is severely compromised. This is manifested in the generally sparse listing of well-supported intrinsic and extrinsic risk factors noted throughout the book, and the extreme paucity of sound epidemiologic studies on preventive measures. Rectifying the current dearth of premium data requires consideration and application of a number of theoretical, conceptual, and logistical issues.

Fundamental Deficiencies

An overview of the recommendations from the chapter authors related to further research highlights the need for a concerted and coordinated approach to the study of injury and injury prevention. Major fundamental deficiencies identified in these reviews include inappropriate study designs, short data-collection periods, inconsistent or poorly delineated definition(s) of reportable injuries, and failure to collect exposure data (or wildly variable measures of exposure if exposure was considered). Appropriately rectifying these features is the minimum required to develop sound descriptive data. A special thematic issue of the *Clinical Journal of Sports Medicine* [2007, **17**(3)], intended to highlight for clinicians and researchers these and other important theoretical and pragmatic sticking points related to compiling valid, reliable and functional information in sports medicine epidemiology, is recommended for additional reading.

Overarching methodologic shortcomings is the almost complete lack of comprehensive surveillance systems in sports, without which no cohesive epidemiologic research can be undertaken but within which all design approaches can be appropriately used. As the strengths, weaknesses, and purpose of various epidemiologic research designs are well known (e.g., Hennekens & Buring 1987; Barss et al. 1998), the need for surveillance infrastructure appears to be the major obstacle to better analyses of sports injuries. In the chapter on boxing, Zazryn and McCrory noted that even for this high-risk activity the "literature is replete with case series and case-control studies" generally focused only on neurologic aspects, and they identified the need for prospective, longitudinal studies. However, without a surveillance system in place, prospective, longitudinal studies are logistically difficult to initiate, leading researchers to use less robust designs (case reports, case series, cross-sectional). Suggestions related to improving surveillance infrastructures are presented at the end of this chapter.

The importance of longitudinal data collection for obtaining an accurate picture of injury risk and risk factors cannot be overemphasized. Research that covers only one event, one season, or one year is limited in its ability to provide strong evidence of the rate or predominant risk factors of injury because it is not possible to determine whether the findings accurately reflect the true, underlying values or whether the results were unusually high or low. In addition, the short time frame means that few such studies have an adequate sample size, which directly influences the power of the study so that "a negative finding could result from a type 2 error (overlooking a true effect), since the studies are too small to detect anything but strong relationships" (Bahr & Holme 2003, p. 390) and positive findings may be spurious. With limited-duration studies, questions related to rates and risk factors in various parts of a season, or between practice and competition, may not be addressable, and for single-event studies in particular, follow-up to determine actual time loss or costs may not be possible (Junge et al. 2006).

Deciding what incidents should be registered in sports injury research (i.e., what qualifies as a reportable injury?) is also an area of considerable inconsistency, with the result that few studies, even in the same sport, are directly comparable. Although the definition chosen should be directly related to the purpose of the study, Junge et al. (2008) pointed out that a broad definition (e.g., "all injuries that receive medical attention") provides the greatest flexibility to researchers, as it can provide information on the total health burden associated with particular sports/events, which is vital for medical planning (staff, supplies), and with additional notation can delineate time-loss injuries, data that are essential for pragmatic risk appraisal, and prioritizing prevention intervention research. Moreover, a broad definition can capture minor/moderate injuries, which cumulatively have the greatest economic impact on the sports health care system (Hodgeson et al. 2007). In sum, the more data that can be extracted from the same collection method, the greater the value of the study. For example, the medical commission of the French Judo Federation has established an excellent approach to this issue and can present data on the total number of injuries associated with competition, the number that resulted in the medical staff interrupting matches, the number that resulted in the athlete withdrawing from competition, and the number that were evacuated to hospital (Barrault et al. 1983; Frey et al. 2004). Because the surveillance system also records exposure data, the rates of these various levels of "injury" and the relative risk of sustaining each by specific subpopulations (gender, age, skill level) can be calculated and examined in a meaningful way. However, Orchard and Hoskins (2007) argued that, at least for team sports, a "match time loss" standard is preferable to broad-based definitions because it is "the cheapest, most functional, most accurate," and most reliable approach, despite certain limitations. Resolving such elemental differences is integral to establishing effective injury databanks.

In addition, many studies fail to assess exposure data or, alternatively, use unique or obscure standards, both of which significantly undermine the value of the study findings in advancing our understanding of the risks involved in sports participation. Lack of a standard metric for exposure data, even within the injury literature for the same sport, makes it difficult to amalgamate findings from different studies. In essence, each study becomes an idiosyncratic "stand-alone" glimpse of injury characteristics rather than a contribution to a global understanding of rates and risk factors in a particular sport or a means of making comparisons across different sports. For example, in examining the literature for the chapter on snowboarding, Russell, Hagel, and Goulet reported at least 11 different exposure metrics. Although the exposure metric must be appropriate for the circumstances and goal of the study, incorporating a standard value, in addition to any special measure(s), would facilitate rate and risk analyses within and across sports. Junge et al. (2008) noted that in sports injury studies, exposure data have generally involved: (a) $10^{2,3}$ athletes, (b) $10^{2,3}$ hours of participation, or (c) $10^{2,3}$ athlete-exposures. The "per-athlete" approach is problematic in that it fails to account for the variability in the actual amount of participation between athletes and can result in inaccurate risk assessment. The use of "per-hour" data is considered the most accurate but is logistically the most difficult to assess accurately and may not make sense for certain sports or for cross-sports comparisons (e.g., injuries per 1,000 hours of 100-m sprints compared to 1,000 hours of association football). Given the limitations of the preceding options, there is a growing consensus that per 1,000 athlete-exposures is the most versatile denominator for sports injury analysis because it is conceptually stable, mathematically flexible, and logistically straightforward (one athlete-exposure can be considered the event of "one athlete participating in one practice or game in which there is the possibility of sustaining an athletic injury" (Caine et al. 1996). Thus, one game of badminton singles would be two athlete-exposures). As with the value of using the broad definition of a reportable injury discussed previously, establishing athlete-exposure as the benchmark does not preclude researchers from using additional denominator calculations for specific purposes, but it does provide a singular point of reference for all. For example, as the elements of practice are different from competition in many sports (e.g., time, intensity, specific activities), researchers may wish to use an additional metric, such as "hours of participation" or refine the definition of athlete-exposure for practice to more accurately capture the risk characteristic of practice.

Future Considerations

With the majority of injury research in sports comprised of one-off efforts (e.g., case studies, prospective studies of one event or one year), often the result of fortuitous circumstances rather than a deliberate, long-range research agenda, it appears that many investigators think of injury epidemiology as a static enterprise designed to capture relatively stable values and relationships. However, as van Mechelen et al. (1992) argued, the process, particularly as it relates to injury prevention, must be considered iterative, consisting of four parts: (1) identifying the extent of the injury problem, (2) uncovering risk factors and mechanisms of injury, (3) using interventions (derived from identified risk factors and mechanisms) to reduce the risk or severity (or both) of injuries, and (4) evaluating the efficacy of the interventions by repeating step 1. In addition, researchers such as Meeuwisse (1994a, 1994b) have pointed out that injury does not result from a single factor but is the end point of the interaction of multiple factors and, as such, multifactorial models of injury need to be incorporated into the theoretical schema of sports injury research. Gissane and colleagues (2001) extended the concept of a multifactoral model into a cyclical framework in which intrinsic and extrinsic factors interact to produce an injury event, the outcome of which, in turn, becomes an additional risk factor for injury, lesser participation, or retirement from participation. The authors posited that this model allows for "appropriate strategies for the prevention of injury at the primary, secondary, and tertiary levels" because "injury is not an endpoint [and] rehabilitation and recovery are part of the continuing process" (p. 2002). Finally, Meeuwisse et al. (2007) incorporated and extended these various lines of thinking to develop a "dynamic, recursive" model that considers how the impact of various risk factors change through the mere fact of participation, regardless of whether injury occurs.

As researchers look to improve their understanding of injury and prevention, they must consider the value of these new theoretical frameworks. However, to appropriately exploit their potential requires additional skills or resources. For example, few researchers in sports epidemiology have attempted to use anything except the most basic analytical techniques (often inhibited by the lack of usable data) but with better-quality data coming from improved surveillance, designs, and methods, complex questions can be asked and answered with more sophisticated analytical procedures. As Bahr & Holme (2003) point out, injuries "are generated by the interplay of several factors" and standard univariate analysis, which precludes using the multifactorial modeling discussed previously, "may be too simplistic" to unravel these relationships. They expanded on the advantages (and limitations) of using multivariate procedures such as logistic regression and Cox proportional-hazards regression models to answer questions related to confounding factors or interaction effects and Dunson (2001) argued for the value of a Bayesian approach to data analysis, including the ability to analyze latent variables, which would be appropriate for the cyclical or recursive modeling of Gissane et al. (2001) and Meeuwisse et al. (2007). Emery (2007) examined the implications of sports injury researchers failing to consider "the fact that individuals within a cluster [e.g., a team] will be more similar than individuals between different clusters" (p. 211) in their analyses of injury and injury-prevention studies and argued for appropriate application of cluster analysis to ensure accurate interpretation of the research outcomes. Finally, no sports epidemiology research has yet taken advantage of multilevel analysis techniques, such as hierarchical linear modeling or generalized linear mixed modeling, to explore the impact of grouping or nesting characteristics (e.g., players nested in teams nested in leagues) in injury-prevention studies. The "possibility of expressing how context [e.g., team membership] affects relationships between individual-level variables [e.g., risk factors and injury rate] is an important reason for the popularity of multilevel modeling" (Snijders 2003) in other disciplines and can expand the scope of research questions in sports medicine epidemiology.

Although what needs to be done from design and methodologic perspectives is clear, the question of how to meet these goals remains largely unanswered. It is apparent from examining the extant literature that the current patchwork of ad hoc injury-focused projects in the majority of sports is inadequate for generating the quality and quantity of data necessary to obtain a clear picture of the scope, nature, and inevitability of injury in these sports or to explore more sophisticated models of injury causes and prevention.

Research must be built into the infrastructure of all sports competitions in concert with medical coverage. Although neither should be an afterthought, this is often the case, especially with low-profile sports or less-than-elite-level participants, such as children and youths. For example, Ganschow (1998) evaluated the quality of medical care for judo competitions in five German states and rated it as poor in local competitions for 42% of events for children/youths, and 26% of events for adults, as compared with 14% at regional/national competitions for adults. Only 2.7% and 5.3% were rated as good at the local level for children/youths and adults, respectively, as compared with 19.6% for regional/national competitions for adults. As appropriate medical coverage tends to be correlated with the perceived inherent risk of injury in sport, the level of competition (with better services for higher-risk sports and/or more prestigious events), or both, and epidemiologic research is linked with medical services, the paucity of comprehensive injury data in most sports and for multiple specific populations (women, children, older adults, athletes with disabilities, beginners) within all sports is inevitable but unacceptable.

The nascent research efforts by the IOC at the 2008 Beijing Games were encouraging and represent one option for improving the overall organization of data collection. For example, the IOC must continue to research its primary competition arenas (the summer and winter Olympic and Paralympic Games, and the Youth Olympic Games scheduled to begin in 2010) and, in addition, support research initiatives with funding and staffing resources for IFs and NOCs. The IFs, in turn, need to coordinate research for their respective world cup competitions and world championships and, in concert with the appropriate NOCs, sustain the research work of the National Governing Bodies (NGBs) for sports under their administrative umbrellas for national-level competitions and national championships. Finally, the NGBs need to be responsible for directing research at subelite levels (e.g., regional/local competitions; recreational and practice data) by providing appropriate medical professionals to cover competitions and training programs through their regional administrative units. The publication of consensus statements on injury definitions and data collection procedures from two important IFs (Fédération Internationale de Football Association [FIFA]; the International Rugby Board) (Fuller et al. 2006, 2007), as well as the agreement statement on concussion arising from joint sponsorship by the IOC, FIFA, and the International Ice Hockey Federation (McCrory et al. 2005), are significant steps in this process and provide models for other IFs and NGBs to follow.

To maximize the acquisition of meaningful data from this system will require developing a cohesive, coordinated set of research questions and long-range goals, elements that have been lacking in the majority of previous studies. To date, few epidemiologic studies have evolved from a deliberate needs analysis and systematic exposition of desired goals on a scale sufficient to produce comprehensive and robust results. Most frequently, studies are guided by the specific circumstances or interests of individual researchers or research groups, even if they are motivated by an existing gap in the literature. There are too few instances of any entity (individual researcher, research group, sports administrative body) prospectively outlining all of the deficiencies in the epidemiologic literature in a sport, methodically prioritizing the importance of each, and ultimately, developing an implementation and reevaluation plan to "close the gap" on what is unknown and form the framework for ongoing investigations.

Ultimately, the purpose of epidemiologic research in sports is to reduce or eliminate injuries and their severity by identifying relevant risk factors and initiating effective prevention programs. Despite some limitations, the work of Simpson et al. (2002) with the "Tackling Rugby Injury" initiative as an outgrowth of the Rugby Injury and Performance Project is one of the few examples of effectively completing this research circle. It is cause for reflection that even with the paucity of empirically supported prevention strategies, few of those that have demonstrated efficacy in research settings (refer to Chapter 31, on "Injury Prevention in Sports") have been widely used. As Finch (2006) has noted, what is effective in a tightly controlled research study may not be effective (or even feasible) in the "real world," and the lack of emphasis on translational research means that potentially beneficial interventions may not be instituted, or instituted effectively, in which case all of the research underpinning the prevention strategy has been for naught. To date, it appears that Chalmers et al. (2004) and Finch (2006) are among the few in sports medicine epidemiology who have attempted to address this important "last" step by examining the factors that impact the likelihood of a prevention strategy being adopted by the target population. As with using advances in research design and analysis, the sports medicine community must avail itself of models related to evaluating research-to-practice protocols that have emerged from other fields to effectively achieve its goals. For example, the RE-AIM model "conceptualizes the impact of an intervention as the product of its reach, efficacy, adoption, implementation and maintenance" (Glasgow et al. 1999), all of which are measurable and modifiable, such that the success of an intervention can be objectively gauged or parameters deliberately altered to achieve the best outcome (e.g., reduced overall injury rate, reduced rate of severe injury, decreased economic burden of injury). This approach has clear value to the mission of sports medicine epidemiologists and needs to be explored in more detail.

There is no doubt that sports participation, at any level, brings with it a wealth of personal and social benefits. Paradoxically, participation produces injury, which not only undermines the individual psychological, physiological, and social benefits of being physically active but contributes to the general public health burden, both directly in terms of medical care and indirectly in terms of lost productivity (Chalmers et al. 1999). Establishing robust epidemiologic research to cast the rate and severity of sports-related injury in high relief and then reducing both by systematically identifying risk factors and subsequently developing effective prevention interventions is an ethical, social, medical, and political imperative and an ever-evolving challenge to researchers.

References

Bahr, R. & Holme, I. (2003) Risk factors for sports injuries—a methodological approach. *British Journal of Sports Medicine* **37**, 384–392.

Barss, P., Smith, G., Barker, S. & Mohan, D. (1998) *Injury Epidemiology: An International Perspective*. Oxford University Press, New York.

Barrault, D., Achou, B. & Sorel, R. (1983) Accidents et incidents survenus au cours des compétitions de judo (in French). *Symbioses* **15**(3), 144–152.

Caine, C., Caine, D. & Lindner, K. (1996) The epidemiologic approach to sports injuries. In:*Epidemiology of Sports Injuries* (Caine, D., Caine, C. & Lindner, K., eds.), Human Kinetics, Champaign, IL, pp. 1–13.

Chalmers, D., Yeo, J., Seward, H., Kolt, G. & Steele, J. (1999) The impact of sports injuries—implications for prevention. *Fifth IOC World Congress in Sport Sciences: Sport Epidemiology Symposium*, Sydney, Australia (October 31–November 5). URL fulltext.ausport.gov.au/fulltext/1999/iocwc/abs149.htm [accessed on January 5, 2008]

Chalmers, D., Simpson, J. & Depree, R. (2004) Tackling rugby injury: lessons learned from the implementation of a five-year sports injury prevention program. *Journal of Science and Medicine in Sport* **7**(1), 74–84.

Dunson, D. (2001) Commentary: Practical advantages of Bayesian analysis of epidemiologic data. *American Journal of Epidemiology* **153**(12), 1222–1226.

Emery, C. (2007) Considering cluster analysis in sports medicine and injury prevention research. *Clinical Journal of Sports Medicine* **17**(3), 211–214.

Finch, C. (2006) A new framework for research leading to sports injury prevention. *Journal of Science and Medicine in Sport* **9**, 3–9.

Frey, A., Rousseau, D., Vesselle, B., Hervouet des Forges, Y. & Egoumenides, M. (2004) Neuf saisons de surveillance médicale de compétitions de judo (in French). *Journal de Traumatologie du Sport* **21**(2), 100–109.

Fuller, C., Ekstrand, J., Junge, A., Andersen, T., Bahr, R., Dvorak, J., Hägglund, M., McCrory, P. & Meeuwisse, W. (2006) Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *British Journal of Sports Medicine* **40**, 193–201.

Fuller, C., Molloy, M., Bagate, C., Bahr, R., Brooks, J., Donson, H., Kemp, S., McCrory, P., McIntosh, A., Meeuwisse, W., Quarrie, K., Raftery, M. & Wiley, P. (2007) Consensus statement on injury definitions and data collection procedures for studies of injuries in rugby union. *Clinical Journal of Sports Medicine* **17**(3), 177–181.

Ganschow, R. (1998) Sportverletzungen im judo: risikoprofil und ansätze für die präverntion [Sports injuires in judo: high risk profile and approaches to prevention] (in German). *Deutsche Zeitschrift für Sportmedizin* **49**(3), 76–81.

Gissane, C., White, J., Kerr, K. & Jennings, D. (2001) An operational model to investigate contact sports injuries. *Medicine and Science in Sports and Exercise* **33**(12), 1999–2003.

Glasgow, R., Vogt, T. & Boles, S. (1999) Evaluating the public health impact of health promotion interventions: the RE-AIM framework. *American Journal of Public Health* **89**, 1322–1327.

Harmer, P. (1991) Athletes, excellence & injury: authority in moral jeopardy. *Journal of the Philosophy of Sport*, **18,** 24–38.

Hennekens, C. & Buring, J. (1987) *Epidemiology in medicine*. Little & Brown, Boston, MA.

Hodgeson, L., Gissane, C., Gabbett, T. & King, D. (2007) For debate: Consensus injury definition in teams sports should focus on encompassing all injuries. *Clinical Journal of Sports Medicine* **17**(3), 188–191.

Junge, A., Engebretsen, L., Alonso, J.M., Renström, P., Mountjoy, M., Aubry, M. & Dvorak, J. (2008) Injury surveillance in multi-sport events—the IOC approach. *British Journal of Sports Medicine* **42**(6), 413–421.

Junge, A., Langevoort, G., Pipe, A., Peytavin, A., Wong, F., Mountjoy, M., Beltrami, G., Terrell, R., Holzgraefe, M., Charles, R. & Dvorak, J. (2006) Injuries in team sports tournaments during the 2004 Olympic Games. *American Journal of Sports Medicine* **34**(4), 565–576.

McCrory, P., Johnston, K., Meeuwisse, W., Aubry, M., Cantu, R., Dvorak, J., Graf-Baumann, T., Kelly, J., Lovell, M. & Schamasch, P. (2005) Summary and agreement statement of the Second International Conference on Concussion in Sport. *British Journal of Sports Medicine* **39**, 196–204.

Meeuwisse, W. (1994a) Assessing causation in sports injury: a multifactorial model. *Clinical Journal of Sports Medicine* **4**(3), 166–170.

Meeuwisse, W. (1994b) Athletic injury etiology: distinguishing between interaction and confounding. *Clinical Journal of Sports Medicine* **4**(3), 171–175.

Meeuwisse, W., Tyreman, H., Hagel, B. & Emery, C. (2007) A dynamic model of etiology of sport injury: the recursive nature of risk and causation. *Clinical Journal of Sports Medicine* **17**(3), 215–219.

Olympic injuries range from basic to bizarre. (2008) URL www.msnbc.msn.com/id/25959884/page/3/ [accessed on August 4, 2008]

Orchard, J. & Hoskins, W. (2007) For debate: Consensus injury definitions in team sports should focus on missed playing time. *Clinical Journal of Sports Medicine* **17**(3), 192–196.

S. Korean rider dies at cross-country event in Doha. (2006) URL theseoultimes.com/ST/?url=/ST/db/read.php?idx=4460 [accessed on June 17, 2007]

Simpson, J., Chalmers, D. & Waller, A. (2002) The New Zealand Rugby Injury and Performance Project: Developing "Tackling Rugby Injury," a national injury prevention programme. *Health Promotion Journal of Australia* **13**, 44–50.

Snijders, T. (2003) Multilevel analysis. In: *The Sage Encyclopedia of Social Science Research Methods (Vol. II)* (Lewis-Beck, M., Bryman, A. & Liao, T, eds.), Sage, Thousand Oaks, CA, pp. 673–677.

van Mechelen, W., Hlobil, H. & Kemper, H. (1992) Incidence, severity, aetiology and prevention of sports injuries: a review of concepts. *Sports Medicine* **14**(2), 82–99.

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