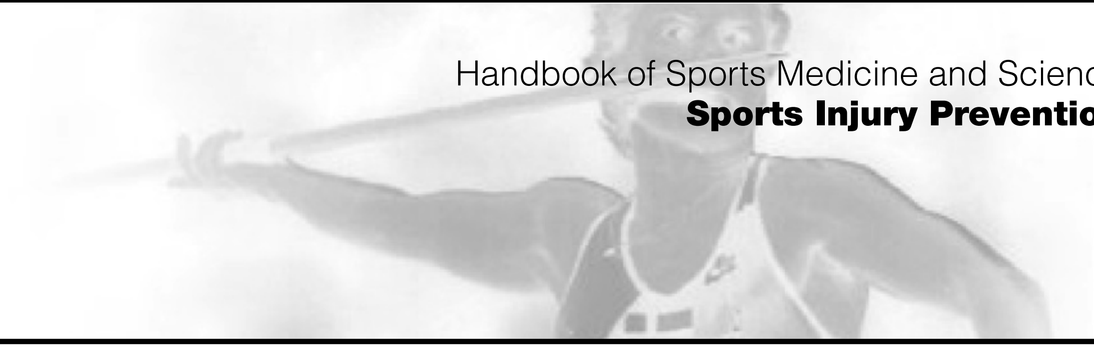
Handbook of Sports Medicine and Science

Sports Injury Prevention



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Handbook of Sports Medicine and Science
Sports Injury Prevention

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Foreword

The objective established in 1991 by the IOC Medical Commission for the Handbook series was the presentation in a clear style and format of basic clinical and scientific information regarding the sports of the Olympic Summer Games and the Olympic Winter Games. Each of the handbooks that have been published during the intervening years was developed by a team of authorities coordinated by editors who had earned international respect and recognition in the areas of sports medicine and the sport sciences.

Since the appearance of the first publication, handbooks have appeared that have dealt with 10 Olympic sports as well as the general topics of strength training and nutrition for athletes. Sections dealing with sports injuries have appeared throughout these handbooks. Two volumes of the other IOC Medical Commission series, Encyclopaedia of Sports Medicine, have been devoted completely to injuries in sport.

The protection of the health of the athletes is one of the IOC's priorities. Therefore, the understanding of injuries and their prevention became one of the focuses of the Medical Commission and the Medical and Scientific Department of the IOC.

The principal objective of this Handbook on Sports Injury Prevention is a comprehensive review of the information currently available regarding the identification of the risk factors for specific injuries in each sport, the understanding of the injury mechanisms, the appropriate conditioning of athletes for the particular sport, and the risk management appropriate to each activity.

The Handbook on Sports Injury Prevention constitutes the most comprehensive review of the preclusion of the occurrence of injuries presently available and each section presents highly practical information based on published science. We welcome this splendid contribution by Roald Bahr, MD, PhD, Lars Engebretsen, MD, PhD, and 36 contributing authors to the literature of sports medicine and sports science.

Preface

In sports, injuries happen. Sometimes they happen by chance, sometimes by intent. Sometimes they are difficult, even impossible, to explain. But frequently there are clear patterns. And when there are patterns, there are also opportunities for reducing the risk of injury.

The objective of this book is to describe those opportunities – for the benefit of everyone playing sports. Although it may be expected that the main readership will be physicians, trainers and physical therapists working with sports teams, the coaching staff is an even more important target group. And although it is assumed that the reader has a basic knowledge of human anatomy and physiology, ultimately the main audience is of course the athlete. With these target groups in mind, we have attempted to create a work that is at once comprehensive in approach, practical in content, and accessible in delivery.

Our intention is to describe a practical approach to the prevention of sports injuries. The first three chapters describe the general principles of injury prevention. Chapter 1 discusses why injury prevention in sports is important, including perspectives on short- and long term consequences for health and performance. Chapter 2 describes the basis for intervention, how information on risk factors and injury mechanisms can be used to identify patterns. Such patterns can be used to identify athletes with a higher risk for injury or situations with a propensity for injury; information which is critical to be able to target and develop preventive programs. Chapter 3 describes how an injury prevention program can be developed and implemented within the team. In this context, a team can also mean a team of athletes competing in individual sports, such as a team of alpine skiers.

One choice we faced when planning this book, was whether to organize the contents per sport or per body part/injury type. One advantage of describing sports-specific programs is that it would be possible to detail measures particular to that sport, for example equipment-related measures such as alpine ski bindings. However, partly because some such information is available already (e.g. vol. V of the Encyclopedia of Sports Medicine series: Clinical Practice of Sports Injury Prevention and Care, ed. P.A.F.H. Renström), we felt that a region-specific approach would be more appropriate. Chapters 4 through 12 therefore describes how the most common sports injury types can be prevented; ankle, knee, hamstring, groin, low back, shoulder, elbow, head and cervical spine injuries. The final two chapters discusses how tendon overuse injuries, which represent a major problem across sports and body region, can be prevented (ch. 12) and how large-scale injury prevention programs can be implemented (ch. 13).

Each of the region-specific chapters includes an introduction outlining how relevant each injury type is in each of the main Olympic sports. In contrast to previous works on sports injury epidemiology, we have attempted to keep this section brief and to the point, answering the key questions:

How common is the injury in question? What is the risk – in my sport? The next section attempts to describe the key risk factors for the injury in question – how to identify athletes at risk. This includes a description of the various internal and external risk factors suggested for the injury in question, emphasizing modifiable risk factors and how the coach/medical team can identify players at risk of injury. In some cases, simple tests or screening methods which can be applied to a team setting are described. This section is followed by a description of the typical injury mechanisms for the injury in question, not just the biomechanics of injury, but also the circumstances leading to injury, such as player behavior, opponent behavior, the playing situation, or other relevant factors. We have also asked all authors to provide a section identifying risks in the training and competition program, a risk analysis to document the parts of the season when athletes are at the greatest risk for sustaining injuries as a result of the training or competitive programs. For some injury types, this type of analysis could be an important basis for planning preventive measures, particularly for the purpose of avoiding overuse injuries during transitional periods. The final – and most important – section of each of these chapters is the section on prevention methods. This section discusses possible ways to prevent the injury in question, and although these may be relevant across sports, the text provides examples from sports where injury prevention has been successful. We have tried to make this section as practical as possible, with examples of take-home ready-to-use programs wherever possible, complete with illustrations of exercises used.

This book is the first of its kind. Never before has anyone attempted to provide a guide to injury prevention – to be applied across different sports. This represents a significant challenge, since there is no model available to guide us in the development of the contents. We wish to thank the authors, who have worked hard to not just provide an up-to-date description of injury prevention methods relevant to their region and injury type, but also to develop a text consistent in content and format across the various chapters. If we have succeeded, the credit belongs to this group of dedicated professionals. If not, the responsibility is ours.

Oslo, September 2008
Roald Bahr & Lars Engebretsen

Chapter 1
Why is injury prevention in sports important?

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This book is a result of the IOC Medical Commission's increasing emphasis on prevention of sports injuries. The numerous health benefits of physical activity have been well documented, resulting in public health support of regular physical activity and exercise. Although beneficial, exercise and sports also have corresponding risks, including that of musculoskeletal injuries. However, at a time when there is an abundance of medical meetings, journals, and papers, some might argue that the last thing we need is a new book focusing on yet another field of research and clinical practice. What would justify such an emphasis on a new and developing field in medicine? First, it must ask important questions not answered by others. Second, the new research field should have the potential to create truly new knowledge, lead to new ways of thinking and lay the foundation for improved health for our patients. This is usually not possible without a multidisciplinary approach, involving a mixture of basic scientists and clinicians. Third, research results from the new field should be publishable in respected journals, recognized and cited by peers, presentable at high-quality meetings, and fundable on competitive grant review. Let us examine each of these issues to see if there is sufficient merit in sports injury prevention research.

Is injury prevention important?

First, is injury prevention important? Epidemiological studies show that of injuries seen by a physician, in Scandinavia, every sixth is sustained during sporting activity (Bahr et al., 2002). Among children, every third hospital-treated injury is the result of sports participation (Bahr et al., 2002). During 1997 and 1998, in the United States, annually there were an estimated 3.7 million sports- and recreation-related emergency department visits annually in the United States, representing approximately 11% of all injury related emergency department visits; 2.6 million visits were among persons aged 5–24 years. The medical charges for these visits were estimated at 500 million US$ annually.

The risk of injury clearly differs between sports, as documented by a study initiated by the IOC Medical Commission in team sports during the 2004 Olympic Games in Athens (Junge et al., 2006). As shown in Table 1.1, while a soccer and handball player suffered one injury every 10th match he or she play, a volleyball player at the elite level only had an injury every 100th match on the average. Not all of these injuries are serious; in fact only about half of all the injuries recorded were

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Table 1.1 Injury risk in selected team sports during the 2004 Olympic Games in Athens.

Sport	Total injury rate[1]	Rate of time-loss injuries[2]
Football		
Men	109 (85–133)	44 (29–60)
Women	105 (74–136)	44 (24–64)
Handball		
Men	89 (64–114)	40 (23–57)
Women	145 (110–180)	36 (18–53)
Basketball		
Men	64 (40–89)	29 (12–45)
Womenv	67 (42–91)	24 (9–39)
Field hockey		
Men	55 (37–72)	24 (12–36)
Women	17 (5–29)	4 (0–10)
Baseball (men)	29 (15–43)	13 (3.2–22)
Water polo (men)	30 (16–44)	9 (1.1–16.3)
Volleyball (men)	11 (1.4–21)	9 (0.2–17)

Source: Junge et al. (2006).
[1] Injury rate is reported as the number of injuries per 1000 player matches (with 95% confidence intervals).
[2] Rate of time-loss injuries is reported as the number of injuries expected to lead to time loss from further training and competition.

expected to cause the player not to continue with subsequent training or match time. Nevertheless, when taking injury severity into account, a research group within the English Football Association found that the overall risk to professional athletes is unacceptably high—approximately 1000 times higher among professional football players than for high-risk industrial occupations (Drawer & Fuller, 2002) (Figure 1.1). Although football and handball rank highest in injury rates of the team sports included in the Olympic summer program, there are actually other sports where the injury rate is considerably higher, for example, ice hockey and the other football codes: American football, rugby, and Australian rules football.

Some injury types, such as serious head and knee injuries, are a particular cause of concern. Head injuries are known to have a high incidence among alpine skiers and snowboarders, especially among snowboarders, and the frequency increases year by year in this group. Head injury is the most frequent reason for hospital admission and most common cause of death among skiers and snowboarders with an 8% mortality rate among those admitted to hospital with head injuries. Among injuries related to football, 4–22% are head injuries. The reported incidence during matches—1.7 injuries per 1000 player hours—incorporates all types of head injuries including facial fractures, contusions, lacerations, and eye injuries (Andersen et al., 2004). The estimated incidence of concussion—0.5 injuries per 1000 match hours—probably represents a minimum estimate due to the problem of defining and grading concussions (Andersen et al., 2004). Although most athletes with head injuries recover uneventfully following a single concussive episode, repetitive mild head trauma may be implicated in the development of cumulative cognitive deterioration. Based on paper and pencil tests, cumulative effects of repeated concussions have been found to cause deterioration in neuropsychological function among athletes in other sports such as American football and boxing, as well as in non-athletes.

The highest incidence of anterior cruciate ligament (ACL) injuries is seen in 15- to 25-year-old athletes in pivoting sports such as football, basketball and handball. This incidence is three to five times higher among women than men (Griffin et al., 2006). In 1970, Kennedy stated that "the anterior cruciate ligament is the most common cause of the exathlete." In other words, the treatment offered at the time did not permit athletes to go back to sport. This is no longer the case, at least in the short term, thanks to the advances in sports medicine research, with major improvements in surgical techniques and rehabilitation programs. Today, most elite athletes are initially able to resume their sports career, should they wish to do so. And although the retirement rate may be higher among athletes with a previous ACL injury compared with healthy athletes, the main concern is the dramatically increased risk of long-term sequelae—like abnormal joint dynamics and early onset of degenerative joint disease. Importantly, we still lack evidence to suggest that reconstructive surgery of either menisci or cruciate ligaments decrease the rate of post-traumatic osteoarthritis (OA). After 10 years, approximately half of the patients display signs of OA, and it appears that the majority of the patients will have osteoarthrosis after 15–20 years (Figure 1.2) (Myklebust & Bahr, 2005). Thus, whereas

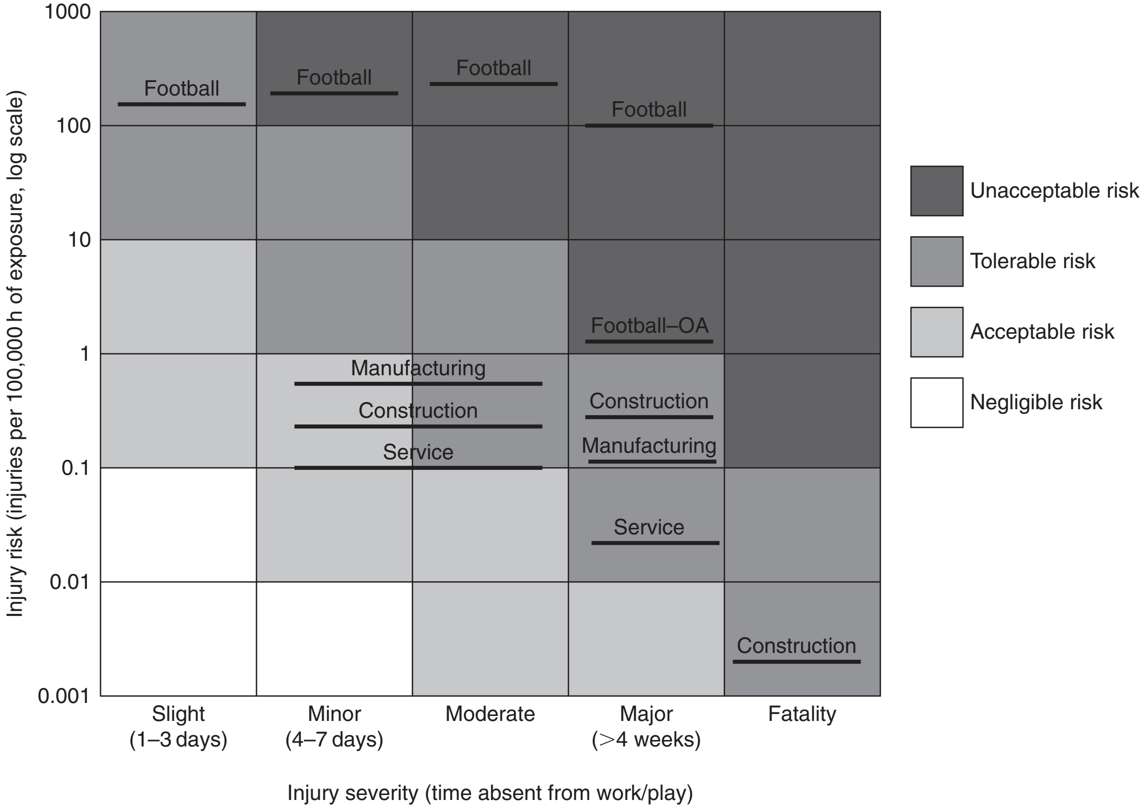

Figure 1.1. Comparison between injury risk (shown on the logarithmic vertical axis as the incidence per 100,000 h of player exposure) and injury risk (shown on the horizontal axis as the duration of absence from work/play, from slight through minor, moderate and major to fatalities) in professional football (Premier League), along with data from the manufacturing, construction and service industries for comparisons. Also, the dark gray areas are classified as unacceptable risk when using industrial standards for risk management. Reproduced with permission from Drawer and Fuller (2002)

developing improved treatment methods for injuries, in general, and ACL injuries, in particular, remains an important goal, it may be even more important to prevent injuries.

Is there an evidence base for injury prevention?

The second issue relates to the potential for new ideas and improved health outcomes. In May 2000, a PubMed search revealed that out of 10,691 papers on athletic injury, there were only six randomized controlled trials (RCTs) on sports injury prevention (Table 1.2). However, a similar search of the literature in December 2007 revealed that sports injury prevention research is emerging as a new field in medicine. While the number of studies on athletic injuries has increased by 43% over the last 7 years, clinical studies and RCTs related to sports injury prevention has increased by 200–300% (Table 1.2). Gradually, congresses in sports medicine, orthopedics, and traumatology include an increasing number of symposia, lectures, and instructional courses on injury prevention issues. Research is also improving in quality, not only in quantity. For example, recent issues of high-impact general medical journals such as the *British Medical Journal* and the *Journal of the American Medical Association* have included several papers related to injury prevention; two case-control studies among

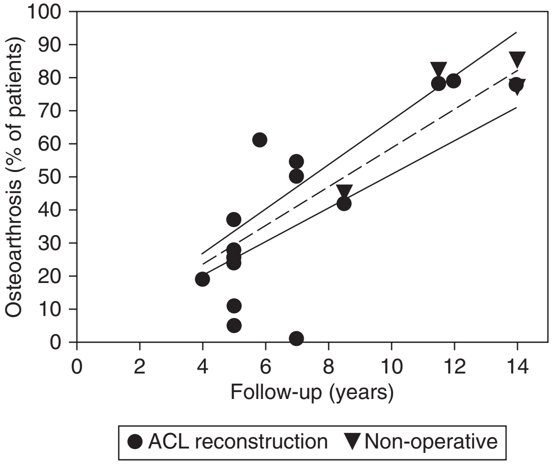

Figure 1.2. Anterior cruciate ligament (ACL) follow-up studies and Osteoarthritis (OA) prevalence. The data illustrate the prevalence of radiographic OA after reconstructive surgery with bone-patella-tendon-bone graft or hamstring graft and after non-operative treatment. The dashed line indicates the forced regression ($y = 6.0t$; $r = 0.85$) between time (t) and OA prevalence (y), with the 95% confidence intervals shown by thin solid lines. Reproduced with permission from Myklebust and Bahr (2005)

Table 1.2 Results of PubMed searches on sports injury research related to treatment and prevention.

Search terms	May 2000	December 2007	Increase (%)
Athletic injury	10,691	15,347	43
& treatment	6,606	9,774	48
& Limit: Clinical trials	182	359	97
& Limit: RCT	87	180	107
& prevention	2,064	3,319	61
& Limit: Clinical trials	29	125	330
& Limit: RCT	21	70	233

Note: Results are shown as the number of items resulting from the search terms shown.

skiers and snowboarders indicating a significant reduction in the risk of head injury with helmet use (Hagel et al., 2005; Sulheim et al., 2006), an RCT demonstrating a 47% reduction in knee and ankle injuries from a structured program of warm-up exercises in adolescent team handball players (Olsen et al., 2005), and an ecological study of a nationwide educational injury prevention program indicating a reduced frequency of spinal cord injuries in rugby (Quarrie et al., 2007). Many major public health and specialty journals are currently publishing new studies in this field. The publication of these studies in highly respected medical, physical therapy and nursing journal illustrates that sports injury prevention is an important public health issue.

Is sports participation healthy?

Sports participation is important from a public health perspective. There is no longer any doubt that regular physical activity reduces the risk of premature mortality in general, and of coronary heart disease, hypertension, colon cancer, obesity, and diabetes mellitus in particular. The question is whether the health benefits of sports participation outweigh the risk of injury and long-term disability, especially in high-level athletes? A study from Finland has investigated the incidence of chronic disease and life expectancy of former male world-class athletes from Finland in endurance sports, power sports, and team sports (Sarna et al., 2000). The overall life expectancy was higher in the high-level athlete compared to a matched reference group (75.6 versus 69.9 years). They also showed that the rate of hospitalization was lower for endurance sports and power sports compared to the reference group (Kujala et al., 1996). This resulted from a lower rate of hospital care for heart disease, respiratory disease, and cancer. However, the athletes were more likely to have been hospitalized for musculoskeletal disorders. A follow-up study revealed that former team sport athletes had a higher risk of knee OA, and other studies have documented an increased risk of hip and knee arthritis among former football players. Thus, the evidence suggests that although sports participation is beneficial, injuries are a significant side effect. To promote physical activity effectively, we have to deal professionally with the health problems of the active patient. This does not only involve providing effective care for the injured patient, but also developing and promoting injury prevention measures actively.

Injury prevention is a complex process. To prevent injury, scientists must first correctly identify one or several risk factors, the mechanisms of injury, devise an effective intervention to modify it, implement the intervention with sufficient compliance, and study the outcome of the intervention with a method that is sensitive enough to detect reductions in the injury rate which are clinically meaningful. When prevention is successful or fails, it may not always be clear which step in this chain of events was deficient. This complexity makes injury prevention difficult, but not impossible. A number of interventions have shown a reduction in injury rates, that is, ACL injuries in team handball and soccer; ankle injuries in soccer, basketball and volleyball; head injuries in hockey and skiing; wrist injuries in snowboarding; and hamstrings injuries in Australian Rules football and soccer. The list is increasing year by year for the benefit of the athlete and the sports.

The future of injury prevention

Do we need to further develop prevention programs in the future? Year by year we seem to have more information about risk factors and their relative roles. If the relative additional risk of having specific risk factors is known, some individuals should probably be advised against participation in certain sports where the risk factor cannot be eliminated. On the contrary, if the effect of eliminating one risk factor after another is known, individuals may be able to participate in sports with low risk if they are compliant with their specific training program. The goal must be to reach a stage where the risk factors are known and where we can assign a relative risk of an injury to individuals. During the preseason examination, individuals with risk factors can then be assigned training programs that have been validated. Even at this stage, future research in this field is necessary. The nature of sports is always changing—becoming faster and generally more demanding. Just think of the difference in alpine skiing over the last 25 years. In almost any sports the same increase in pace is seen. Thus, research on risk factors and injury mechanisms must be ongoing and intervention studies crucial.

In an evolving field such as this, international cooperation is critical. The involvement of the IOC, which highlights sports injury prevention research in this book, improves the dissemination of information around the world. In addition, this book initiative has been supported by all of the major sports and sports medicine organizations, which bodes well for the future.

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Chapter 2
A systematic approach to sports injury prevention

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Injury prevention in sport has numerous benefits. These include greater health of the individual; longevity in the activity; and reduced costs to the individual, the sport, the health care system, and society. An obvious benefit is the potential for better performance through injury prevention. This may be particularly relevant when trying to motivate athletes, coaches, and sports teams to focus on injury prevention. The likelihood of success is greater if all the best players on the team are available for team selection. And the chance of success is nil if you are injured when the Olympics start!

Prevention can be grouped into three broad categories of primary, secondary, and tertiary prevention. Primary prevention is the goal of most prevention activity, and is what most people think of when they consider prevention. That is, primary prevention involves the avoidance of injury (e.g., ankle braces being worn by an entire team, even those with no history of previous ankle sprains). If primary prevention activities are successful, an individual will not sustain injury in the first place.

This differs from secondary prevention which involves appropriate early diagnosis and treatment once an injury has occurred. The aim here is to ensure that the injury is optimally cared for to limit the development of disability, and is what most people think of as treatment (e.g., early RICE treatment of an ankle sprain).

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Finally, tertiary prevention is the focus on rehabilitation to reduce and/or correct an existing disability attributed to an underlying disease; what most people think of as rehabilitation (e.g., in the case of a patient who has had an ankle sprain, this would involve balance board exercises and wearing an ankle brace while gradually returning to sport).

Sequence of injury prevention research

In 1992, van Mechelen outlined a sequence of injury prevention research (Figure 2.1). This conceptual model can be successfully applied by sports medicine staff, as well. First, according to the research model, the magnitude of the problem must be identified and described in terms of the incidence and severity of sports injuries. If you are responsible for a team, this would involve monitoring injury risk on a continuous basis by recording all injuries within the squad, as well as training and match participation (often called “exposure”). As a second step in injury prevention research, the risk factors and injury mechanisms must be identified that play a part in causing sports injuries to occur. For the medical team and coaching staff, this could involve systematic steps to examine the athletes and their training and competition program. The third step is to introduce measures that are likely to reduce the future risk and/or severity of injuries. Such measures should be based on information about the risk factors and the injury mechanisms as identified in

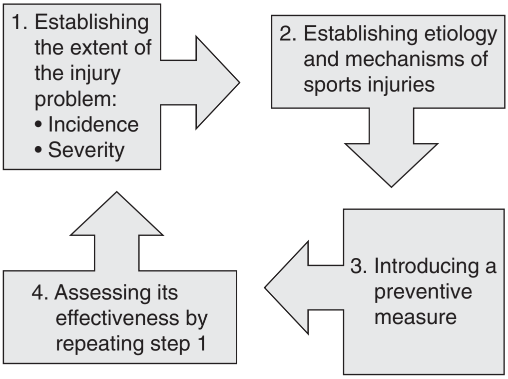

Figure 2.1. A model of injury prevention research—the four steps in sports injury prevention (van Mechelen et al., 1992)

the second step. Finally, the effect of the measures must be evaluated by repeating the first step. From a researcher's standpoint, it is preferable to evaluate the effect of preventive measures by means of a randomized controlled trial. For the team staff, continuous surveillance of the injury pattern within the team will reveal whether the changes occur in the injury risk (providing the medical staff realize that changes in patterns of injury over time in a single team can be due to many different factors).

Injury surveillance

The object of surveillance is to enumerate the extent of injury in a given group or population. In this book, the rate of specific injury types across different sports will be reported. Based on surveillance data from previous studies, we can learn which injury types should be targeted when considering injury prevention in different sports. Surveillance within a specific team, league, or sport organization can also highlight potential areas of prevention that might be unique to that group. A soccer coach may want to focus on hamstring strains, knee and ankle sprains, whereas a baseball coach may decide to consider shoulder and elbow problems when planning his training and competition program. However, injury rate is not the only factor to be considered. Injury severity is also an important concern. For example, serious knee injuries or head injuries may warrant particular attention, not based on injury rate alone, but because they can potentially result in permanent disability and even death.

However, when comparing results between studies in different sports and different sports settings, there are a number of important characteristics of surveillance that must be considered, including the injury definition. There is also the question of diagnostic coding or classification of injury and issues surrounding the count of injury and reinjury, and assessment of severity.

Injury definition

Defining what constitutes an injury is not as easy as it may seem at first glance, and there have been many different approaches to injury definition in the past. A consensus statement was issued in 2006 in the sport of football (soccer) stating that the broadest definition of injury would be any event occurring as a result of participation in sport (Fuller et al., 2006). Injury was then further classified into *medical attention injuries*; those that required assessment or treatment by a medical practitioner. A further sub-division was *time-loss injuries*; those causing a player to miss one or more practices or games or sessions. The important point in any research regarding injury surveillance is that one must know in advance exactly what will be counted, and this must be consistent across all people and all groups recording injury. This is important to ensure consistency both within a given period of surveillance and over time between different periods of surveillance.

Injury classification

Similarly, consensus has been achieved regarding the classification of injury into various body regions and injury types (Fuller et al., 2006). These can be refined more fully within the context of sport through the use of diagnostic coding systems that are tailored specifically for sport.

Injury severity

Injury severity can be classified on the basis of the level of tissue damage, the type of structure injured, or the nature of the injury itself. However, within the context of sport the most meaningful measure is likely the amount of time an individual is unable to participate in their customary activity of training or competition. Obviously, career-ending injuries or injuries causing permanent disability, or even death, are a particular concern. The "time lost" can be counted in days or sessions (games or practices) missed. The total time lost from injury within a team can be used to monitor the quality of not only the efficiency of the medical team in diagnosing and treating injuries, but also the injury prevention program within the team.

Injury recurrence

In counting injuries, it is important to realize that all injuries are not isolated events. That is, some injuries are a recurrence of something that has happened previously, either pre-dating or during the same period of data collection. Fuller et al. (2007) have recommended that recurrence be grouped into "exacerbations" and "reinjuries." Exacerbations should not be counted as a new injury event, but any time missed should be attributed to the first injury. In contrast, reinjuries should be counted as a separate injury event with their own time loss. If injury surveillance within a team reveals an unusually high rate or proportion of recurrences, this could mean that injury rehabilitation is insufficient or that athletes are allowed too early return to play after previous injuries.

Exposure

With injury surveillance one can look at numbers of new injuries over a period of time. However, within the context of sport where there is varying degrees of participation (and therefore exposure to the potential of injury), it is more meaningful to capture injuries in reference to the amount of time that a given individual participates. Participation can be counted in hours or sessions. From this, an injury rate, or incidence rate, can be calculated. In this book injury incidence is typically reported as the number of injuries per 1000 hours of player exposure. This allows injury risk to be compared between different sports and different groups.

Determining the causes of injury

If one is to prevent injury, the causes of injuries must be determined. First, one must identify those factors associated with an increased risk of injury ("risk factors").

Risk factors

Although all individuals possess certain characteristics or factors, they are considered risk factors if they increase the chance of an injury occurring. However, the assessment of risk can be complex, since most factors in sport do not act in isolation. A risk factor may be part of a collection of other factors that, together, produce a picture of "sufficient cause" for an injury to occur. Sometimes, one specific risk factor is necessary and without this factor, an injury will not occur (Meeuwisse, 1994; Meeuwisse et al., 2007).

There are many factors that impact on the potential occurrence of injury. There are internal or intrinsic risk factors that are part of an athlete's make up that may make them predisposed to injury. Then, they begin to participate and are exposed to external or extrinsic factors, which may make them susceptible to injury. These risk factors (often in combination) will determine whether a specific event or force will produce an injury (Figure 2.2).

In some cases the risk factor that is being evaluated is not the cause of injury. Interestingly, if the factor is shown to be associated with an increased risk of injury it is considered a risk factor. This allows this factor to be a valid predictor or marker of injury. However, removing the risk factor may not necessarily prevent injury if a causal relationship does not exist.

Etiology

In some instances the immediate cause (or etiology) of injury is obvious. However, all is not always what it appears to be. Even in the most obvious examples, there is often more than one factor that has led to the injury. In the case of a macro-traumatic injury, such as a kick to another player's leg resulting in a muscle contusion, there

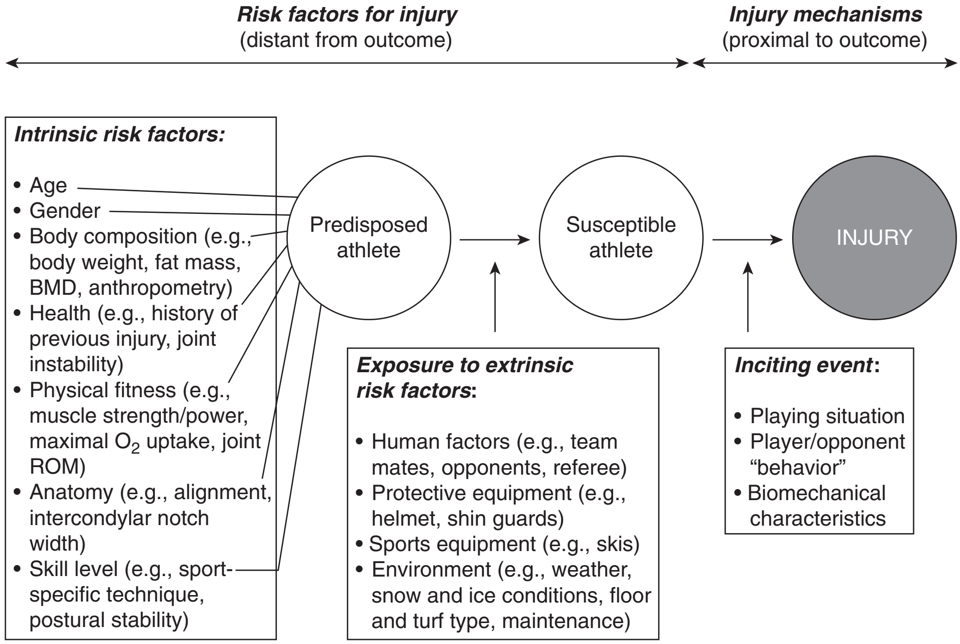

Figure 2.2. A model of injury causation (Meeuwisse, 1994; Bahr & Krosshaug, 2005)

may have been factors related to the injured player, the opponent, the equipment, the playing environment, etc., which all could have contributed to the injury occurring, or its severity. Therefore, it is important to take a more encompassing view of etiology or causation.

A model has been developed in the past to account for a number of different variables that may contribute to injury. Meeuwisse (1994) outlined a model wherein an athlete begins with a certain set of characteristics (Figure 2.2). These are typically referred to as intrinsic risk factors or internal factors which may predispose the athlete for injury. This includes athlete characteristics: factors such as age, maturation, gender, body composition, and fitness level. One factor that consistently has been documented to be a significant predictor is previous injury—almost regardless of the injury type studied. Intrinsic factors such as these interact to predispose for injury, or in other cases protect from injury. Examples of factors which may make an athlete less predisposed to some, but not all, injury types include fitness-related factors such as muscle mass, strength, balance, and neuromuscular control.

An athlete then begins to participate in sport within a certain environment and is exposed to extrinsic risk factors. These may include equipment and field conditions, for example, floor friction in indoor team sports, snow conditions in alpine skiing, a slippery surface (running track), very cold weather, or inappropriate footwear. Extrinsic factors may also reduce injury risk, such as the wearing of protective equipment. Exposure to such external risk factors may interact with the intrinsic factors to make the athlete more or less susceptible to injury. When intrinsic and extrinsic risk factors act simultaneously, the athlete may be at far greater risk of injury than when risk factors are present in isolation.

The final link in the chain is the inciting event, which is usually referred to as the injury mechanism—what we see when watching an injury situation. Each injury type and each sport does have its typical patterns, and for team medical and coaching staff it is important to understand the typical injuries and mechanisms in their sport (Bahr & Krosshaug, 2005).

It has been recognized more recently that this process should not be seen as linear and static.

That is, it does not have a clear starting and ending point in the context of sport. Athletes participate in sport over typically a long period of time and bring with them characteristics of prior training as well as other sport experience and injury. Moreover, they carry their intrinsic risk factors with them into repeated exposure to extrinsic risk factors and many potentially inciting events, most of which never result in injury.

Therefore, one limitation of the model is that it is not obvious how the athlete's training routine and competitive schedule can be taken into consideration as potential causes, and the model has therefore traditionally mainly been used to describe the causes of acute injuries. For overuse injuries, the causative factors can sometimes be distant from the outcome. For example, for a stress fracture in a long distance runner the inciting event is not usually the single training session when pain became evident, but the training and competition program he or she has followed over the previous weeks or months.

Another limitation is that repeated exposure may produce adaptation, either in the course of normal training or as a consequence of being exposed to potentially injurious events. Overuse or gradual onset injuries are typically produced as a result of high training loads over a period of time. In some athletes, these training loads will result in adaptation and the athlete will actually become stronger and therefore have an improved (reduced) set of intrinsic risk factors. In other athletes, this may result in tissue breakdown and microtraumatic changes that would worsen (increase) their intrinsic risk factors.

Ultimately, this happens on a cyclical basis for every single participation in sport (Meeuwisse et al., 2007). As athletes are exposed to the playing environment and face different events, some of those will become an inciting event and therefore a mechanism for injury. Others, however, produce no injury but rather adaptations in the athlete, which may be biomechanical, structural, behavioral, etc. Then, these athletes repeatedly participate in sport, creating a dynamic cycle wherein repeat participation can result in either injury or no injury.

Therefore, it is important to keep in mind that risks will change under repeated participation. This is not just because of external changes such as differences in weather or playing surfaces or equipment worn. Internal risk factors can also change as a result of participation. Specifically, an athlete's susceptibility to tissue-level damage may be reduced as strength improves with repeated use or as technique becomes adapted in a positive manner. At the same time, repeat participation can produce microtrauma that weakens tissue and increases susceptibility to injury. In addition, athletes may change their behavior, their style of play or even their choice of protective equipment based on a perceived susceptibility or risk of injury. These circumstances do not tend to remain constant even within one player over the course of time. Rather, adaptations or changes may occur during a season through both training and competition. The behavior of these factors have been described in more detail by Meeuwisse et al. (2007).

Modifiable and non-modifiable risk factors

Assuming that a risk factor is a cause of injury, the best way to prevent injury is to change the risk factor. For example, a risk factor of muscle weakness can be overcome with a strengthening program, or a risk factor of poor proprioception can be improved by balance re-training. In addition, if artificial turf were a risk factor, it could be minimized by playing on grass.

However, in some cases, the risk factor cannot be changed, eliminated, or modified. Even so, non-modifiable factors (such as gender) may be equally important in injury prevention if they can be used to target intervention measures to those athletes who are at increased risk. For example, anterior cruciate ligament (ACL) injuries have been shown to be four to six times more common among female athletes than male athletes in some sports, such as soccer, basketball, and handball. Based on this, female athletes should be the primary target group for ACL injury prevention programs in these sports.

The mechanism of injury

In some cases, the key to injury prevention may lie with the injury mechanisms, not with the risk factors. For example, one may consider being struck in the face by a hockey puck or stick as a completely random event, which could occur regardless of intrinsic or extrinsic risk factors. If defenders and attackers are hit as often as goalies, it may not be possible to identify the player at risk. And even if the chance of being struck were twice as high for goalkeepers, a face mask would be the obvious preventive measure and the key question would be how to design such a mask, and not who should wear it.

To fully understand the inciting event, and the ultimate chain in the factors leading to injury, it is helpful to use a comprehensive model, which accounts for the events leading to the injury situation (playing situation, player, and opponent behavior), as well as includes a description of whole body and joint biomechanics at the time of injury (Bahr & Krosshaug, 2005). Ideas for preventive measures may originate from each category of information, depending on the injury type in question.

For some injury types, the key to prevention may lie with the events leading to the injury situation (e.g., the playing situation, player behavior, or opponent behavior). For example, to prevent head injuries in soccer the first obvious question is: What strikes the head? The ball? Or is it a head-to-head clash with an opponent in a heading duel? Or the opponent's arm or elbow? Or do head injuries typically result when falling and hitting the ground? Recent studies from elite male soccer on the national and international level have shown that the commonest mechanism involved heading challenges and the use of the upper extremity with elbow to head contact. In the majority of the elbow to head incidents, the elbow was used actively at or above shoulder level (Figure 2.3). From these findings stricter rule enforcement and even changes in the laws of the game concerning elbow use can be made to reduce the risk of head injury.

In other sports, it may be more important to have detailed knowledge of the biomechanics. For example, to design an appropriate hockey helmet, it is necessary to have an accurate estimate of the impact forces involved in the game, such as when a falling player hits the ice. Other examples of factors which may be important to understand

Figure 2.3. Typical mechanism for head injuries in soccer. Elbow to head contact in a heading duel. The player on the left uses his right elbow actively above shoulder level to prevent the opponent player from reaching the ball. Reproduced from Bahr and Krosshaug (2005) with permission

and describe the injury mechanisms are shown in Table 2.1. Such information can be obtained from a variety of research methods, each with its own strengths and limitations. These include interviews of injured athletes, analysis of video recordings of actual injuries, clinical studies (where the clinical joint damage findings are studied to understand the injury mechanism through examination, diagnostic imaging, or surgical exploration), in vivo studies (measuring ligament strain or forces to understand ligament loading patterns), cadaver studies, mathematical modeling and simulation of injury situations, or measurements/estimation from "close to injury" situations. For most injury types, one research approach alone will not be sufficient to describe all aspects of the injury situation. A broader and more precise understanding could be attained by combining such research approaches as athlete interviews, video analysis,

Table 2.1 Categories of injury mechanism descriptions with examples of elements and descriptions.

Category	Elements	Examples of factors describing the injury mechanism			
		Non-contact ACL injury in basketball	**ACL injury in a mogul skiing jump landing**	**Knockout in boxing**	**Lower leg stress fracture in football**
Playing (sports) situation	Team action	Fast break	Course steepness	Uppercut, Hook	Exposure to matches and training (total load)
	Skill performed prior to, and at, the point of injury	Zone defense	Jump elements (e.g., twist, helicopter)	Counterattack	Midfielder with defensive and offensive tasks (i.e., many runs in matches/training)
	Court position	Charging	Jump height and length	Foot work	Hard working team
	Player position	Cutting		Forced into the corner/to the ropes	Frequency of duels
	Ball handling	Setting up for a shot		Ring-side referee decision	
		Defensive rebound		Inter-boxer distance	
		Man-to-man defense			
Athlete/opponent behavior	Player performance	Effort	Rhythm and balance prior to the jump	Awareness	Effort
	Opponent interaction	Perturbation by opponent	Concentration	Aggressiveness	Toe/heel runner
	Player attention	Intention	Balance	Punching power	Jumping technique
		Foot firmly fixed to the floor	Boot-binding release	Punching speed	Duel technique
		Intention	Visual control	Balance	
		Technical foul	Jumping technique		
			Over-rotation		
			Falling technique		
Whole body biomechanics	Description of whole body kinematics and kinetics	Sideways translation	Linear and angular momentum	Center of mass velocity	Stride length
		Rotation of the body around the fixed foot	Energy absorption	Punching force	Stride frequency
		Speed at impact	Center of mass to the rear	Punching direction	Vertical excursion
		Foot in front of center of mass		Weight distribution on the legs	Ground reaction forces
					Knee flexion angle
Joint/tissue biomechanics	Detailed description of joint/tissue kinematics and kinetics	Valgus moment	Shear forces	Energy transfer	Bending moment
		Pivot shift of the tibia relative to the femur	Anterior drawer	Head acceleration	Shear forces
		Notch impingement	Intercondylar lift-off	Pressure distribution and localization	Surface/shoe dynamics
			Loading rate		

Reproduced from Bahr and Krosshaug (2005) with permission.
ACL = anterior cruciate ligament.

and clinical studies, or by combining video analysis and studies using cadavers, dummies, or mathematical simulations. The multifactorial nature of sport injuries is important to consider in these studies to understand why certain forces lead to injury in some cases, but not in others. Examples will be presented in the subsequent chapters dealing with specific injury types.

Developing intervention methods and programs

The third stage in van Mechelen's approach is the introduction of prevention measures. The development of injury intervention programs depends to a large extent on the previous step wherein causes of injuries are identified. Strategies for injury control have been developed from other research areas, particularly from research on motor vehicle accidents. One such model, the injury prevention matrix, has two dimensions (Table 2.2). One dimension relates to whether the measure is designed to avoid accidents altogether (pre-crash measures), to avoid injury even if an accident occurs (crash measures), or whether it aims to minimize the consequences of an injury (post-crash measures). The other dimension relates to whether the measure targets the individual, the environment, or perhaps equipment used. Other categories are also possible along this dimension. Although Haddon (1980) originally developed the injury prevention matrix for motor vehicle accidents, it represents a useful approach for analyzing potential injury prevention methods when applied to sports.

Table 2.2 Haddon's matrix applied to sport injury prevention: Measures introduced to prevent sport injuries.

	Pre-crash	Crash	Post-crash
Athlete	Technique, Neuromuscular function	Training status, Falling techniques	Rehabilitation
Surroundings	Floor friction, Playing rules	Safety nets	Emergency medical coverage
Equipment	Shoe friction	Tape or brace, Ski bindings, Leg padding	First-aid equipment, Ambulance

Pre-crash measures

Measures related to the pre-crash stage have been developed to counteract potential injury-causing situations by preventing accidents altogether. In sports, examples of *athlete*-related pre-crash measures include ensuring adequate, sport specific, physical conditioning of athletes, increasing their skill level, and improving neuromuscular control and agility to avoid situations where they might get injured. Psychosocial variables may be addressed in an effort to influence the athletes' resiliency and injury vulnerability. In addition, sport-specific screens may help identify athletes at risk for injury and modify their risk prior to participation. Examples of *environmental* pre-crash measures include modifying the friction of the playing surface (too high may lead to twisting injuries to the lower extremity, too low may lead to slipping and falling injuries) or changing regulations to avoid dangerous plays. *Equipment*-related pre-crash measures include modifying shoe friction and choosing cleat length according to the playing surface and weather conditions. All of these measures are based on modifying risk factors that have been shown to be a cause (or part of a cause) of injury.

Crash measures

Measures related to the second stage, the crash stage, have been developed to protect the athlete against injuries if a potentially harmful situation arises. These measures mainly focus on assisting athletes to withstand the forces involved when a collision or a fall occurs. *Athlete*-related crash measures could involve, for example, a general strength-training program, flexibility program, or falling techniques. *Environmental* crash measures include safety nets to avoid falling alpine skiers from flying into the crowd or soft mats protect gymnasts failing to dismount or falling down from an apparatus. There are many examples of *equipment*-related crash measures in sports, such as release bindings for alpine skiing, helmets and pads for various sports, taping and braces for joints, shin guards, and eye protection.

Post-crash measures

Post-crash measures are designed to minimize the damage resulting from an injury and the risk of reinjury (which is a strong risk factor for sports injuries), and mainly relates to the chain of medical treatment provided after an injury. Post-crash measures in sports may include providing adequate medical services during sports events (personnel and equipment); training athletes and coaches to provide adequate on-field first aid, including quick evacuation procedures to a hospital in the case of severe injuries, adequate rehabilitation programs for injured athletes and ensuring appropriate medical clearance before they return to competition.

Active versus passive measures

Injury prevention measures can also be categorized as active or passive (Haddon, 1974). Examples from motor vehicle accident prevention are seat belts (active) which require the individual to fasten them, and air bags (passive) which do not require the operator to take any action. In between these extremes there are measures which require some action by individuals. An example is where specific safety gear is required in the rules of the sport; that is, this requires some action by the individual, but this action is a prerequisite to be allowed to participate. This is the case for helmet wear in ice hockey and competitive skiing and snowboarding. In contrast, among recreational skiers and snowboarders, helmets are still not required by most skiing resorts. In this setting, helmet use must be considered an active measure, dependent on education and attitudes with significant barriers in terms of cost and availability.

The distinctions are not merely classifications. They have direct, practical relevance. Historically, passive approaches, when available, have a spectacularly more successful record in injury prevention outside of sport. This is also the case within the sports context, where there is a long tradition for mandating safety equipment, and specific safety standards for sports venues. For example, in leagues where the type of facial protection in ice hockey is optional, players at the varsity/college level have been shown to choose the minimum level mandated. There is an inherent level of risk that athletes appear to be willing to absorb, which may be a barrier to adopting active measures.

Implementing injury prevention programs

Once methods with a potential for prevention have been identified, there is a need to carefully develop the prevention measures, assess them under ideal conditions, and consider the implementation context (Finch, 2006).

An important part of the development of interventions is first testing their *efficacy*. This means that under ideal conditions, they are tested to determine if the intervention works. This is typically done in a controlled research setting with extensive monitoring and measurement of compliance with the intervention. This differs from *effectiveness*, which is where an intervention is implemented in a broader context, often in a community or sport setting, where the degree of attention to the program and monitoring is much less.

If we use the analogy of a drug, efficacy would be the question of whether the drug works under controlled conditions of ideal use. Effectiveness would measure whether the drug worked in a given patient, who may be affected by side effects, convenience of use, etc. Therefore, the culture of sport has a major influence on the effectiveness of intervention programs. Specifically, attitudes and behaviors or historical biases within the sport may prove to be either incentives or barriers to effective implementation of injury prevention programs. To build on our earlier example, the move to mandate full facial protection in adolescent ice hockey was initially resisted due to concerns from sport administrators that the nature of the game would be altered, and from medical personnel that such changes could lead to an increase in neck injuries.

Therefore, the development of injury prevention programs must take into consideration more than the biomechanics of injury or their specific