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ECSS Position Statement 2009: Prevention of acute sports injuries

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POSITION STATEMENT

ECSS Position Statement 2009: Prevention of acute sports injuries

KATHRIN STEFFEN[1], THOR EINAR ANDERSEN[1], TRON KROSSHAUG[1], WILLEM VAN MECHELEN[2], GRETHE MYKLEBUST[1], EVERT A. VERHAGEN[2], & ROALD BAHR[1]

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Abstract

To maximize the health benefits of sports and exercise and to minimize the direct and indirect costs associated with injuries, developing and adopting injury prevention strategies is an important goal. The aim of this ECSS consensus paper on injury prevention is to review current evidence on injury prevention methods and training programmes aimed at reducing the most common or severe types of acute injuries. The target audience is everyone involved in protecting the health of the athlete, including coaches, referees, medical staff, sports governing bodies, as well as athletes themselves. Effective sports injury prevention requires successful implementation of efficacious interventions. This paper reviews the main mechanisms and risk factors for acute injuries to the head, shoulder, elbow, hand/wrist, groin, thigh, knee, and ankle, as well as the evidence supporting various strategies to prevent them. Approaches that have been shown to be successful include: (1) using equipment designed to reduce injury risk, (2) adopting the rules of play, and (3) specific exercise programmes developed to reduce injury risk. Sports organizations should adopt available injury prevention strategies as part of their policies.

Keywords: *Athletic injury, prevention, risk factors, injury mechanisms, safety equipment, exercise programmes, health policy*

Introduction

The physical activity guidelines of the American College of Sports Medicine recommend adults achieve 20–30 min of vigorous exercise at least 5 days a week for optimum functional capacity and health (Haskell et al., 2007). Numerous health benefits of physical activity have been well documented, resulting in public health support for regular physical activity and exercise. 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 (Haskell et al., 2007; LaMonte, Blair, & Church, 2005).

The question is whether these health benefits outweigh the risk of potential injury and long-term disability associated with sports participation, especially at the elite level (Engebretsen & Bahr, 2009). A Finnish study of the incidence of chronic disease and life expectancy of former elite athletes revealed that the rate of hospitalization for heart disease, respiratory disease, and cancer was lower for former athletes than for a control group of non-athletes. However, former athletes were more likely to have been hospitalized for musculoskeletal disorders (Kujala et al., 1996), and a follow-up study showed that former team sport athletes had an increased risk of knee osteoarthritis (Kettunen, Kujala, Kaprio, Koskenvuo, & Sarna, 2001). Thus, although evidence suggests that sports participation is beneficial from a public health perspective, injuries also have significant negative side-effects in both the short and long term.

Some injury types are of particular concern, either because they can be severe, such as head and knee injuries, or common, such as ankle sprain or hamstring strain injuries. These represent a considerable problem for the athlete, the team and, given the

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popularity of sports, for society at large. Thus, to maximize the health benefits of sports and exercise and to minimize the direct and indirect costs associated with injury, developing methods to prevent sports injuries is a necessary goal. However, it should be kept in mind that the risk of injury will, to a certain extent, always persist when participating in sports.

To develop effective injury prevention strategies, it is critical to know the causes of injuries. As described by Meeuwisse and colleagues (Meeuwisse, Tyreman, Hagel, & Emery, 2007), one important goal is to map the intrinsic and extrinsic factors that put an athlete at risk of injury. In addition, a precise description of the inciting event – the injury mechanism – is necessary (Bahr & Krosshaug, 2005).

The aim of this ECSS consensus paper on injury prevention is to review current evidence on injury prevention strategies and training programmes aimed at reducing the most common or severe types of acute injuries. To better understand the rationale of effective injury prevention measures, each section also briefly describes the most important injury characteristics, risk factors, and mechanisms. General recommendations on the implementation of injury prevention strategies are presented in the final section of this paper.

Methods

Individuals with extensive experience in prevention research related to each of the body regions covered here were identified. Each of them was asked to write a section outlining the current status regarding the characteristics, risk factors, and mechanisms of injury to a specific region/injury type, as well as methods to prevent the injury in question. We did not require them to do a formal search of the literature, although most did to supplement their own literature database. Their draft was circulated among the group members until a final version, which was acceptable to all members, was arrived at.

Head

Injury characteristics

Head and neck injuries are common across many sports. Horse riding, ice hockey, skiing/snowboarding, soccer and other football codes (e.g. American and Australian football) are sports where head injuries can result from a fall or from direct contact with sports equipment or other athletes, either by chance or through poor individual skills or rule violations. Recent reviews (Ackery, Hagel, Provvidenza, & Tator, 2007; Hagel, 2005) clearly show that a head injury is the most frequent reason for hospital admission and the most common cause of death among skiers and snowboarders. Fortunately, serious head injuries are rare. The majority (90%) of head injuries are minor, defined as mild concussions (Straume-Næsheim, Andersen, Dvorak, & Bahr, 2005). Concussions typically result in rapid but short-lived impairment of neurological function that resolves spontaneously. Although most athletes with head injuries recover uneventfully following a single concussive episode, repetitive mild head trauma may cause cognitive impairment (Kirkendall, Jordan, & Garrett, 2001; Straume-Næsheim et al., 2005). However, computerized neuropsychological testing did not reveal any impairment from heading exposure or previous concussions in a cohort of professional soccer players (Straume-Næsheim et al., 2005).

Risk factors

Several risk factors for concussive injuries have been suggested. There is agreement in the skiing and snowboarding literature that beginners have an increased injury risk in general and a higher risk for head injuries in particular (Ackery et al., 2007; Hagel, 2005). In snowboarding, for instance, beginners tend to lose their balance more easily, which can result in a backwards fall with an impact to the back of the head. Snow parks with half pipes, rails, and other slope modifications are popular and may contribute to an increased risk of head injury as individual ability is often overestimated (Ackery et al., 2007; Hagel, 2005). The risk factors for catastrophic head and neck injuries are not known.

Mechanisms

Head injuries in sports arise mainly due to impacts with an opposing player, the ground/surface or equipment. In soccer, a blow of the elbow or arm to the opponent's head, as well as a head-to-head contact are the main mechanisms for concussions (Andersen, Árnason, Engebretsen, & Bahr, 2004a; Fuller, Junge, & Dvorak, 2005). In skiing/snowboarding, concussions mainly result from a fall or landing that results in head contact with the ground, while even more severe head injuries may follow from collisions with other skiers or objects, such as trees, rocks or lift towers (Hagel, 2005).

Prevention

Two main approaches have been used to prevent head injuries: using a helmet and rule modifications.

Helmets or padded headgear are used in many high-energy and collision sports to prevent head injury. A meta-analysis, based on five well-conducted case-control studies on pedal cycle helmets in transport and recreation, have confirmed that helmets provide a 63–88% reduction in the risk of head, brain, and severe brain injury for cyclists of all ages (Thompson, Rivara, & Thompson, 2000). In recreational skiing and snowboarding, there is solid evidence to show that using a helmet is associated with a 22–60% reduction in head injury rates (Hagel, 2005; Macnab, Smith, Gagnon, & Macnab, 2002; Sulheim, Holme, Ekeland, & Bahr, 2006). Thus, it is strongly recommended that recreational skiers and snowboarders wear helmets. There are no data from competitive cycling, skiing or snowboarding, but helmets are compulsory according to competition regulations for these and several other sports. Protective equestrian helmets are also widely recommended. Interestingly, since helmets were made compulsory for professional jockeys in 1993–94, no significant improvements in concussion rates have been observed (McCrory & Turner, 2005). Research on padded headgear (soft shell helmets) indicates that they do not reduce the incidence of concussion or serious head injury in rugby union football (McIntosh et al., 2009), and similarly, data from soccer (Andersen et al., 2004a) and Australian rules football (McIntosh & McCrory, 2005) suggest that currently available head gear is unlikely to reduce the incidence of concussion.

Rule modifications represent one strategy to reduce the risk of collisions and head impacts in sports, albeit direct scientific evidence is lacking. Studies from elite soccer show that approximately 40% of all concussions can be attributed to elbow and arm impacts in heading duels (Andersen et al., 2004a; Fuller et al., 2005). As a result, FIFA introduced a stricter rule before the 2006 World Cup, making contact to an opponent's head with the elbow/upper arm during heading duels a "red card" offence. In ice hockey, injury prevention programmes are becoming effective in reducing the number of injuries, especially head, cervical spine, and spinal cord injuries when banning checking from behind (McIntosh & McCrory, 2005).

Shoulder

Injury characteristics

Acute shoulder injuries are common in sports that involve powerful and intentional body contact, including some of the football codes and ice hockey, but they are also common in sports that are characterized by high-energy falls on the shoulder, such as in skiing, snowboarding, ice skating, and cycling.

The severity of an acute shoulder injury depends on the direction of the forces and the anatomical structure affected. Most acute shoulder injuries are minor, resulting in soft tissue contusions around the shoulder. More severe trauma may result in a shoulder dislocation, clavicle fracture, acromioclavicular or sternoclavicular joint dislocation, or a fracture of the upper humerus (Krogsgaard, Safran, Rheinlænder, & Cheung, 2009).

Risk factors

There is no evidence available on risk factors associated with acute shoulder injuries.

Mechanisms

An acute shoulder injury occurs either directly as a result of a fall or blow to the shoulder, or indirectly by transmission of forces through the arm.

Prevention

There are no reports in the literature of methods to protect an athlete from an acute shoulder injury. However, any measures to reduce the risk of falls in sports should reduce the risk of shoulder injury. Shoulder pads can theoretically spread the forces from an impact over a larger area of the body and absorb energy, just like a helmet. In American football, shoulder pads protect the shoulder by dissipating the forces. No study, however, has proved the effect of shoulder pads on reducing the risk of shoulder injury. In addition, hard shoulder pads have the disadvantage that they can hurt other players, particularly if they are used to butt other players (Krogsgaard et al., 2009). Proper falling techniques can help potentially to lessen the direct impact placed across the shoulder joint by learning to roll when landing from a fall, rather than landing directly on the shoulder. Head-first and diveback sliding techniques in baseball and softball can result in upper extremity injuries. However, changing techniques (e.g. banning sliding or forbidding head-first/diveback sliding) is impractical and unsatisfactory to players, and instructional courses regarding injury prevention have proved ineffective since players did not attend (Janda, 2003). Even if direct evidence from team handball is lacking, the adoption of strict penalties for tackling the attacker's arm from behind and holding the player's arm when shooting is thought to prevent acute lesions to the shoulder joint. In summary, there is limited information on the risk factors for, or mechanisms, of acute shoulder injuries, and hence for effective prevention strategies.

Elbow

Injury characteristics

Acute elbow injuries are most common in (1) contact and collision sports (e.g. American football, rugby, and martial arts), (2) sports that place an athlete at elevated heights (e.g. high jump, ski jumping, and gymnastics), and (3) high-speed sports (e.g. alpine skiing, speed skating, and cycling). Also sports such as weightlifting, boxing, shot put, and javelin place acute and heavy loads across the elbow joint during training and competition and expose the elbow to a potential injury risk. Athletes who fall on an extended elbow with the hand in full supination can suffer a number of injury types, including bone bruises, ligament strains, muscle contusions, and skin abrasions, and in the worst cases fractures and dislocations, and even injury to neurovascular structures (Hutchinson & Andrews, 2009).

Risk factors

There is no evidence available on risk factors associated with acute elbow injuries.

Mechanisms

An acute elbow injury can occur via a direct impact to the elbow (e.g. by a fall or a collision) or by an indirect impact resulting in torques across the elbow, such as falling on an outstretched hand – the classical injury description. When the elbow is hyperextended and when moments and forces are excessive, the collateral ligaments will rupture and damage the anterior capsule. If the forces continue, the elbow will dislocate. In judo, for instance, an athlete is allowed to place the opponent's elbow in an elbow lock, a position of hyperextension. Indeed, if the athlete on the receiving end of this manoeuvre does not "tap-out" to concede defeat, continued force may lead to an elbow dislocation (Hutchinson & Andrews, 2009).

Prevention

There has been limited research on injury prevention methods, although it has been suggested that elbow injuries may be prevented through protective padding and education of athletes on how to fall properly (Hutchinson & Andrews, 2009). Minimizing risk exposures and energy transfer during falls could be accomplished via rule enforcement, more severe penalties for violations, or rule changes. An example that has been shown to be effective was limiting the height of cheerleader towers, which, in turn, reduced the potential energy and risk of injury from falls (Boden, Tacchetti, & Mueller, 2003). In judo, banning the ability of a competitor to hyperextend the elbow and subsequently dislocate it until his opponent taps out (gives up) would likely reduce the risk of elbow injuries in judo (Hutchinson & Andrews, 2009). Unfortunately, similar to traumatic shoulder injuries, there is limited evidence on how to prevent acute shoulder injuries. However, as for acute shoulder injuries, many acute elbow injuries are simply accidents that occur during the routine performance of a high-risk sport.

Hand/wrist

Injury characteristics

Sprains of finger and wrist joints as well as fractures of the wrist and fingers are typical in ball sports and other sports involving falling activities/accidents. Wrist fractures are common in snowboard sports (Hagel, 2005; Langran and Selvaraj, 2004). Wrist injuries account for 8% of injuries among elite snowboarders (Torjussen & Bahr, 2005, 2006), and up to 32% among recreational boarders (Langran & Selvaraj, 2004; Machold et al., 2002). In less serious cases, falls result in sprains of the wrist joint (Hagel, 2005). "Skier's thumb" is a tear of the ulnar collateral ligament of the first metacarpophalangeal joint, leading to instability of the joint (Mogan & Davis, 1982), while volleyball players can tear the radial collateral ligament of the same joint when playing defence ("volleyball thumb") (Bahr & Reeser, 2003). Most other finger injuries in, for example, volleyball and team handball are mild ligament injuries with which the athlete continues to train or compete, with or without exposed fingers taped.

Risk factors

Finger sprains take time to heal, and a history of a previous finger sprain exposes this finger to new injuries. Novice snowboarders are 2–3 times more likely to injure their wrist than experienced boarders (Goulet, Hagel, Hamel, & Légaré, 2009; Langran & Selvaraj, 2004; Machold et al., 2002). Snow parks with half pipes, rails and jumps contribute to an increased risk of wrist sprains and fractures as a result of poor or overestimated physical and technical ability (Hagel, 2005).

Mechanisms

Complicated fractures of the wrist or forearm may occur as a result of a direct fall or of an unsuccessful jump, typically seen in skiers and snowboarders. When balance is lost, snowboarders, unlike skiers, cannot "step out" a leg to recover the lost balance, as both feet are firmly attached to the board. The instinctive protective reaction is to reach out to break the landing, thus placing the wrist and fingers at risk of injury (Machold et al., 2002). The typical mechanism for skier's thumb is when a skier falls with the ski pole left in the hand forcing the thumb into adduction and extension (Browne, Dunn, & Snyder, 1976). The mechanism of finger sprains in volleyball and team handball is similar: hyperextension when the ball unexpectedly hits the finger during defence or blocking.

Prevention

There is agreement in the literature that most wrist fractures in snowboarding can be prevented by use of wrist protectors, at least among beginners (Rønning, Rønning, Gerner, & Engebretsen, 2001; Russell, Hagel, & Francescutti, 2007). Wrist protectors are, beside helmet use, one of the simplest strategies to prevent injuries in snowboarding. For every 50 snowboarders who wear a wrist guard, one wrist injury will be averted (Russell et al., 2007). However, the optimal type of wrist guard to most effectively prevent wrist injuries has not been identified. There is no conclusive evidence whether or not wrist guards increase the risk of shoulder, shoulder girdle or elbow injuries (Hagel, 2005; Russell et al., 2007). For skiers, strapless poles have not been shown to decrease the incidence of skier's thumb. However, if skiers are trained to discard the pole during a fall, the risk of injury might be reduced (Fricker & Hintermann, 1995).

One obvious way to try and reduce the risk of injuries to the upper limb in general and the wrist joint in particular is to adopt the correct falling techniques and avoid landing on an outstretched hand. Finger sprains among team sport players may be prevented by prophylactic taping of the exposed fingers, especially fingers with previous ligamentous injuries.

Groin

Injury characteristics

The pelvis is the centre of load transfer from the upper extremities and the torso to the lower extremities and vice versa, and a number of muscle groups interact to stabilize the region and facilitate energy transfer around the pelvic and hip region, including the adductors, iliopsoas, abdominal, and erector spinae muscles. Groin injuries are among the top six most cited injuries in soccer, rugby, American football, ice hockey, speed skating, swimming, and athletics, accounting for more than 10% of all injuries and 20–40% of all muscle strain injuries (Maffey & Emery, 2007). A strain to the groin muscles may be acute but often becomes chronic in nature. Suffering from persistent groin injuries results in extensive rehabilitation and longstanding pain (Jansen, Mens, Backx, Kolfschoten, & Stam, 2008; Macintyre, Johson, & Schroeder, 2006); as an example, 40% of groin injuries in soccer result in more than one week out, and 10% in more than one month out (Maffey & Emery, 2007).

Risk factors

There is clear evidence that a previous strain of the groin muscles on the same side is a strong predictor for a recurrent injury (Emery, Meeuwisse, & Hartmann, 2005; Hägglund, Waldén, & Ekstrand, 2006; Steffen, Myklebust, Andersen, Holme, & Bahr, 2008a). This may be due to scar tissue formation in the muscle or tendon or inadequately rehabilitated strength or flexibility (Árnason et al., 2004; Emery et al., 2005; Steffen et al., 2008a). Other intrinsic risk factors believed to be involved in groin injuries are reduced adductor strength and flexibility of the hip abductors (Árnason et al., 2004; Maffey & Emery, 2007; Verrall et al., 2005). Decreased adductor muscle strength and an imbalanced adductor-to-abductor muscle strength ratio have been shown to predict groin strain injuries. Ice hockey players were 17 times more likely to sustain an adductor muscle strain if adductor strength was less than 80% of abductor strength (Tyler, Nicholas, Campbell, & McHugh, 2001). Reduced flexibility of the abductor and adductor muscles has been suggested as a risk factor for groin strain injuries (Árnason et al., 2004; Ekstrand & Gillquist, 1983; Verrall et al., 2005). However, the evidence is conflicting (Maffey & Emery, 2007), as it is for age and sports exposure as risk factors for groin injuries (Árnason et al., 2004; Maffey & Emery, 2007).

Mechanisms

As groin injuries often show a transition into an overuse condition, the exact moment of injury and the injury mechanisms are hard to establish. Athletes who develop groin problems are often engaged in sports involving kicking, rapid changes of direction, accelerations and decelerations (Macintyre et al., 2006). The adductor muscles may be acutely strained during an eccentric contraction (e.g. in a forced abduction), most likely when the limb is in abduction. This could be a sudden resistance caused by an opponent's foot in an attempt to reach a ball or a sliding tackle in soccer, or the eccentric force of the adductor muscles attempting to decelerate the leg during a stride in ice hockey. The adductor muscles can also be strained in a forceful concentric contraction, as during a kick after a ball in the air. The iliopsoas muscle can be acutely strained if a forceful hip flexion is interrupted suddenly, as if tackled or hitting the ground when kicking, but also during an eccentric contraction (Árnason et al., 2004; Maffey & Emery, 2007; Meeuwisse et al., 2007).

Prevention

A previous groin injury is the best established risk factor, emphasizing the need for adequate rehabilitation of the primary groin injury before returning to sports (Árnason et al., 2004; Hägglund et al., 2006; Steffen et al., 2008a). It is unclear whether stretching of the adductor/abductor and iliopsoas muscles can prevent groin injuries. However, a functional flexibility of these muscles and range of motion of the hip joint may be important (Árnason et al., 2004).

As many groin injuries occur during eccentric loading, reduced eccentric strength of the adductor muscles has been suggested as a possible risk factor. However, studies on different athlete populations (ice hockey, soccer) do not provide conclusive evidence for general strengthening exercises as a prevention method (Maffey & Emery, 2007). Nevertheless, an intervention study including specific strength training of the adductor muscles (static, concentric, and eccentric), as well as core stability exercises for the pelvic muscles showed a highly significant effect in the treatment of adductor-related groin injuries (Hölmich et al., 1999). However, this programme has not been evaluated as a primary prevention method, although such exercises are commonly included in general prevention programmes for lower extremity injuries.

Thigh

Injury characteristics

Common thigh injuries are contusions to the anterior and lateral thigh and strains to the quadriceps or hamstring muscles. A hamstring strain is the most common type of injury in many sports, particularly in the football codes, which are characterized by sudden accelerations and decelerations, often followed by changes of direction, and eccentric muscle activity during sprinting and kicking (Árnason et al., 2004; Askling, Tengvar, Saartok, & Thorstensson, 2008; Hägglund et al., 2006; Mjølsnes, Árnason, Østhagen, Raastad, & Bahr, 2004). Recent studies suggest that the proportion of hamstring strains has increased in soccer during the past decade, as the sport has become more physically demanding with more frequent and higher intensity runs (Árnason et al., 2004; Hägglund et al., 2006). Sports characterized by slow stretching beyond the usual movement of the muscles, in particular hip flexion (e.g. dancing), also have high rates of hamstring injuries (Askling et al., 2008).

Risk factors

The two factors most consistently associated with a hamstring strain injury are a history of previous injury and age (older players with higher risk) (Árnason et al., 2004). Some studies indicate that decreased hamstring strength (concentric and eccentric), low hamstring-to-quadriceps strength ratio, and a side-to-side difference in hamstring strength could be risk factors for hamstring strains (Murphy, Connolly, & Beynnon, 2003). Poor flexibility of the hamstring muscles has also been suggested as a risk factor for muscular strains (Murphy et al., 2003). However, there is a paucity of evidence, and the methodology has been poor, thereby not allowing definitive conclusions to be drawn.

Mechanisms

Most hamstring strains occur during maximal sprinting activities in the late swing phase, when the hamstring muscles are loaded eccentrically to decelerate the forward movement of the leg, or at foot-strike, in the transition from eccentric to concentric muscle action (Árnason, Andersen, Holme, Engebretsen, & Bahr, 2008; Askling et al., 2008; Proske, Morgan, Brockett, & Percival, 2004). It has therefore been postulated that eccentric overload could cause tearing in the muscle tendon unit (Árnason et al., 2004; Garrett, 1990; Maffey & Emery, 2007).

Prevention

Based on the injury mechanism, it has been suggested that eccentric strength is important to prevent hamstring strains. There is good evidence that eccentric strength training of the hamstring muscles increases hamstring muscle torque more effectively than concentric hamstrings training (Askling, Karlsson, & Thorstensson, 2003; Mjølsnes et al., 2004) and reduces the incidence of hamstring strains in elite male soccer players (Árnason et al., 2004; Askling et al., 2003; Mjølsnes et al., 2004). The Nordic hamstring lower exercise is a partner exercise in which the athlete attempts to resist a forward-falling motion of the upper body using the hamstring muscles to maximize loading in the eccentric phase. In a study on Norwegian and Icelandic male soccer players, this exercise reduced the risk of hamstring strains by 65% (Árnason et al., 2008). There is little or no evidence in the literature to suggest that flexibility training alone can prevent hamstring strains in soccer or other sports. One explanation may be that most hamstring strains occur during maximal sprinting, when the hamstring muscles are not stretched towards their maximum range (Árnason et al., 2008; Askling et al., 2008; Verrall et al., 2005). Eccentric hamstring training using the Nordic hamstring exercise has been included in several general lower extremity injury prevention programmes targeting young athletes (Gilchrist et al., 2008; Mandelbaum et al., 2005; Olsen, Myklebust, Engebretsen, Holme, & Bahr, 2005; Soligard et al., 2008; Steffen, Myklebust, Olsen, Holme, & Bahr, 2008b).

Knee

Injury characteristics

Typical injuries to the knee are ligament tears of the collateral or cruciate ligaments; these may be associated with meniscal tears, or cartilage and bone damage of varying severity (Griffin et al., 2006; Renström et al., 2008). Anterior cruciate ligament (ACL) injuries are common and serious, and are associated with an increased risk for early osteoarthritis. The majority of ACL-injured athletes will develop osteoarthritis within 15–20 years, regardless of treatment (Lohmander, Östenberg, Englund, & Roos, 2004; Myklebust & Bahr, 2005; von Porat, Roos, & Roos, 2004). Athletes from pivoting sports such as soccer and other football codes, team handball, and basketball are at risk of sustaining such injuries (Hootman, Dick, & Agel, 2007; Myklebust et al., 2003). Alpine skiing is another activity associated with high risk for knee and ACL injuries (Pujol, Blanchi, & Chambat, 2007).

Risk factors

As for most other injury types, recent studies have suggested that a history of knee injury is a risk factor for a subsequent knee (Hägglund et al., 2006; Steffen et al., 2008a) or ACL injury (Faude, Junge, Kindermann, & Dvorak, 2006; Waldén, Hägglund, & Ekstrand, 2006). Female athletes are reported to have a three- to six-fold higher incidence of non-contact ACL injuries than their male counterparts (Hewett, Myer, & Ford, 2006b). However, the reasons for the gender gap are not clear. Various researchers have suggested differences in anatomy, as well as hormonal and neuromuscular function as potential reasons for the gender gap (for reviews, see Griffin et al., 2006; Renström et al., 2008; Shimokochi & Shultz, 2008). However, there are only a few well-designed prospective studies available, most of which assessed only one risk factor in isolation. ACL injuries can most likely not be attributed to one single factor and large-scale studies are needed to assess how different risk factors act in combination to put the female athlete at risk.

Thus, there is a paucity of evidence linking all these potential risk factors to non-contact ACL injuries, and a great deal of controversy exists on the importance of the different intrinsic risk factors. From the available evidence, it appears that the predictive value of static anatomic properties such as knee alignment, Q-angle, knee geometry, and leg length is limited (for reviews, see Griffin et al., 2006; Renström et al., 2008; Shimokochi & Shultz, 2008). Differences in mechanical properties of the ACL may be another link to the association between ACL tensile properties and injury risk (Chandrashekar, Mansouri, Slauterbeck, & Hashemi, 2006).

There is a consensus emerging from the literature that the likelihood of incurring an ACL injury does not remain constant during the menstrual cycle, with a significantly greater risk during the pre-ovulatory phase than during the post-ovulatory phase (Hewett, Zazulak, & Myer, 2007).

Compared with anatomical and hormonal risk factors, neuromuscular risk factors are more easily addressed by prevention training. It has been shown that females exhibit greater quadriceps dominance, and have less muscle stiffness and muscle strength. However, none of these factors have been assessed in prospective ACL injury risk factor studies and, consequently, it is not possible to determine the relative importance of these factors. To date, only one study has documented a link between dynamic knee valgus motion and ACL injury risk (Hewett et al., 2005). However, the limited sample size (only 9 ACL ruptures) means that the results of this study must be interpreted with caution. Deficits in neuromuscular control of the trunk have also been shown to be associated with knee injury risk (Zazulak, Hewett, Reeves, Goldberg, & Cholewicki, 2007).

Investigations from Australian rules football (Orchard, 2002) and team handball (Olsen, Myklebust, Engebretsen, & Bahr, 2004) suggest that a high shoe–surface friction is connected to an increased risk of ACL injury.

Mechanisms

ACL injuries are commonly non-contact in nature and can occur during plant and cut manoeuvres or during landings. Although most ACL injuries are non-contact by definition, the movement patterns often involve perturbation by an opponent, such as body contact prior to the injury (Krosshaug et al., 2007a). However, even if these few details are known, we still lack vital knowledge about the injury mechanisms. A complete biomechanical description should quantify whole-body and knee kinematics, loading directions, magnitudes, and rates (Krosshaug, Andersen, Olsen, Myklebust, & Bahr, 2005).

The biomechanical mechanisms for non-contact ACL injuries are widely debated. The two most discussed theories involve the quadriceps drawer mechanism and valgus loading. Proponents of the first theory argue that ACL injuries result from loading in the sagittal plane only, primarily as a result of anterior shear forces caused by forceful quadriceps contraction when landing or cutting (Yu & Garrett, 2007). This mechanism was demonstrated in a cadaver study (DeMorat, Weinhold, Blackburn, Chudik, & Garrett, 2004), but was criticized for not taking ground reaction forces into consideration. Others argue that knee abduction must be involved in the injury mechanism (Quatman & Hewett, 2009). This theory is partly based on video analyses of ACL-injured athletes where valgus or valgus collapse are frequently reported (Krosshaug et al., 2007a; Krosshaug, Slauterbeck, Engebretsen, & Bahr, 2007b; Olsen et al., 2004). The combination of external rotation and valgus can possibly result in femoral notch impingement (Fung & Zhang, 2003).

Furthermore, anterior tibial translation induced by a high tibiofemoral compression and tibial plateau inclination has been proposed as a possible loading mechanism (Meyer & Haut, 2008). Internal rotation of the tibia on a relatively extended knee is suggested as an ACL injury mechanism by cadaver studies (Markolf et al., 1995), by athlete interview studies (Myklebust, Maehlum, Holm, & Bahr, 1998), and by video analysis (Olsen et al., 2004). However, to make conclusive statements on the mechanisms of non-contact ACL injuries, new, sophisticated methods of video analysis (Krosshaug et al., 2007a) combined with other research approaches such as clinical studies and cadaver simulation or mathematical simulation studies are needed (Krosshaug et al., 2005).

The mechanisms of knee injuries in alpine skiing and snowboarding are likely to be different from those in team sports and at least among recreational skiers. According to Ettlinger and colleagues (Ettlinger, Johnson, & Shealy, 1995), the two main mechanisms are the so-called "phantom foot" (i.e. internal rotation in deep flexion due to canting of the inside edge of the tail of the ski) and the "boot-induced anterior drawer mechanism".

Prevention

Injury prevention programmes have been developed to reduce the risk of ligamentous knee injuries in general, and ACL injuries in particular (Hewett, Ford, & Myer, 2006a; Renström et al., 2008). They are generally based on the assumption that modifying the dynamic biomechanical risk factors can prevent injuries. Successful prevention programmes alter the dynamic loading of the knee joint through neuromuscular training. Based on the likely injury mechanisms, it is recommended that athletes avoid knee valgus and land with knee flexion to absorb landing forces (Hewett, 2006a; Krosshaug et al., 2007a; Renström et al., 2008). Training programmes that incorporate plyometrics aim to result in safe levels of valgus stress to the knee and alterations in neuromuscular control patterns (Hewett et al., 2006a). As shown in several well-designed intervention studies from soccer and team handball, programmes incorporating one or more exercise components to modify dynamic control of the lower limbs have resulted in remarkable reductions in the risk for ACL injuries (Gilchrist et al., 2008; Mandelbaum et al., 2005; Myklebust et al., 2003) or lower extremity injuries (Olsen et al., 2005; Soligard et al., 2008; Pasanen et al., 2008). Balance training alone, and all homed-based training without instruction and feedback on proper movement technique (lower limb alignment, two-feet landings), is probably not as effective as when it is combined with other types of neuromuscular exercise stimuli (Hewett et al., 2006a; Söderman, Werner, Pietila, Engström, & Alfredson, 2000).

Evidence from research on alpine skiers shows that an educational programme to increase awareness of and modify behaviour in high-risk situations can prevent ACL injuries (Ettlinger et al., 1995).

Ankle

Injury characteristics

An acute lateral ligament injury to the ankle (ankle sprain) represents the dominant injury type in many sports. Most ankle sprains result in an absence from training and competition for not more than a week. Nevertheless, because they are so common in many sports, ankle sprains account for a substantial part of the total injury load. In female youth soccer, for instance, up to 40% of all injuries are ankle sprains (Le Gall, Carling, & Reilly, 2008; Söderman, Adolphson, Lorentzon, & Alfredson, 2001; Steffen, Andersen, & Bahr, 2007), and in volleyball they account for up to 50% of all reported injuries (Bahr & Bahr, 1997; Verhagen et al., 2004). From a public health perspective, ankle sprains therefore constitute a large part of the medical costs due to sports injuries (Verhagen, van Tulder, van der Beek, Bouter, & van Mechelen, 2005).

Risk factors

The only well-documented and probably by far strongest risk factor for an ankle sprain is a previous sprain sustained in the previous 12 months. Studies on various athlete groups found a two- to five-fold increased risk for a lateral ankle ligament injury after suffering a prior ankle injury (Árnason et al., 2004; Steffen et al., 2008a; Verhagen et al., 2004). There is strong evidence that an ankle sprain negatively affects neuromuscular control, believed to be due to trauma to mechanoreceptors of the ankle ligaments causing proprioceptive impairment (Freeman, 1965). As a result, a previously injured ankle is exposed to an increased risk of re-injury (Árnason et al., 2004; Steffen et al., 2008a; Verhagen et al., 2004). There is conflicting evidence about the injury impact of other intrinsic risk factors, such as ankle joint laxity or decreased dorsiflexion of the ankle (Árnason et al., 2004). Anatomic foot type, when classified as pronated, supinated or neutral, does not appear to be a risk factor for ankle sprains.

Mechanisms

Common mechanisms of ankle sprains are tackling, running or landing on uneven ground or the foot of another player. Two specific injury mechanisms are reported in soccer: (1) player-to-player contact with impact by an opponent on the medial aspect of the leg just before or at foot strike, resulting in a laterally directed force causing the player to land with the ankle in a vulnerable position; and (2) forced plantar flexion where the injured player hits the opponent's foot when attempting to shoot or clear the ball (Andersen, Flørenes, Árnason, & Bahr, 2004b; Giza, Fuller, Junge, & Dvorak, 2003). In volleyball, ankle sprains typically occur at the net, resulting from contact between the blocker and the opposing attacker across the centreline or when a blocker lands on a team-mate's foot when participating in a multi-person block (Bahr & Bahr, 1997; Verhagen et al., 2004).

Prevention

Athletes with a history of ankle sprains should be targeted, especially those who sustained such an injury during the preceding 12 months. Ankle proprioception is critical to keep the ankle in a safe "neutral" position, and this ability is often impaired after injury. External support (bracing, taping) has been shown to reduce the risk of re-injury in athletes with a history of ankle sprains, but not in athletes with no previous history (Surve, Schwellnus, Noakes, & Lombard, 1994; Tropp, Askling, & Gillquist, 1985). A cheaper, well-investigated and highly effective prophylactic measure is balance training. Such neuromuscular training is thought to improve proprioception by re-establishing and strengthening the protective reflexes of the ankle (Verhagen et al., 2004). Exercises on balance boards or mats have been shown to reduce the risk of ankle sprains by as much as 50% (Emery, Rose, McAllister, & Meeuwisse, 2007; Olsen et al., 2005; Verhagen et al., 2004). However, as for external ankle support, the effect appears to be limited only to athletes with a history of previous sprains. It is also important to note that specific technical training to avoid vulnerable situations may be effective, at least in volleyball (Bahr, Lian, & Bahr, 1997). In soccer, late tackles resulting in laterally directed blows to the lower leg serve to put the ankle in a vulnerable position when landing or running (Andersen et al., 2004b; Giza et al., 2003). More specific wording of the rules of the game regarding late tackles, in particular two-footed tackles, with stricter penalties, may prevent ankle injuries (Andersen et al., 2004b; Giza et al., 2003).

General conclusions

In a review of the present literature, we found varying evidence on the prevention of acute sports injuries. Although much research has been conducted to help reduce lower extremity injury risk, there is much less evidence on injury risk factors and mechanisms and, consequently, on the prevention of acute upper extremity injuries, such as injuries to the hand, wrist, elbow, and shoulder. Also, several types of injury have not been included in this paper, partly because they are rare or simply because there are no data available on prevention. For Achilles tendon ruptures, for example, both factors apply. There is, to our knowledge, no data on prevention, but a limited amount on risk factors.

In spite of many promising efforts on injury prevention, a better understanding of injury risk factors and mechanisms will help us to optimize current injury prevention strategies, such as exercise programmes, subsequently resulting in fewer injuries, a higher lifelong activity in sports, and lower costs for the public health system.

Recommendations for injury prevention

Three strategies that have proved to be successful in preventing injuries are: (1) using equipment designed to reduce injury risk, (2) adapting the rules of play, and (3) specific exercise programmes developed to reduce injury risk. Effective sports injury prevention requires successful implementation of efficacious interventions. This, in turn, requires knowledge about the implementation context including how people, their attitudes and safety (or risk) behaviours interact with these interventions (Finch & Donaldson, 2009). In other words, true injury prevention can only be achieved if some form of behavioural change can be invoked in all individuals involved in an athlete's safety and health, including coach, referee, and the athlete him or herself. A number of the acute injuries observed may be prevented if athletes participate in sports within the limits of their personal qualifications, physical condition, and avoid risky situations. Therefore, one of the major goals should be to establish injury prevention habits early in life.

Equipment

Helmets have been introduced in skiing, snowboarding, horse riding, ice hockey, cycling, and baseball. In some sports, their use is strongly recommended; in others, helmets are compulsory when competing. In sports in which falls and collisions are part of the game, elbow and shoulder pads are expected to reduce upper extremity injury risk. Similarly, wrist guards are effective in protecting against wrist injuries, at least in snowboarding. However, although such external prophylactic measures are shown to be efficacious, a true reduction of injury risk requires the equipment to be used by the athlete.

Fair play and rules of the game

Many of the rules and regulations that govern sports have been put in place to protect the health of the athlete. Coaches and athletes have a responsibility to play by the rules (fair play), and referees are responsible for penalizing behaviour known to cause injuries. Appropriate referee training emphasizing the safety aspects of the rules is important. Decisions to change rules can be used actively in making the sport safer for athletes, and such rule changes can follow from systematic analyses of injury mechanisms. Examples include checking from behind in ice hockey, holding of the arm in team handball, and elbowing the opponent's head/neck when heading in soccer.

Exercise/training

The benefits of preventive exercise training on lower limb injury risk have been documented in several trials. There is conclusive evidence that neuromuscular training assists in the reduction of ankle and knee ligament injuries, and that eccentric strength training can prevent muscular strains of the hamstrings and groin.

Comprehensive neuromuscular training programmes combining plyometrics, strength, balance, sport-specific technique, and agility exercises can improve biomechanical measures related to lower extremity injury risk (Hewett et al., 2006a,b; Myer, Ford, & Hewett, 2004). While training preventive exercises, emphasis should be placed on a proper landing technique, a soft landing on the forefoot, and engaging knee and hip flexion upon landing. A two-foot landing is encouraged whenever possible. In cutting and landing manoeuvres, athletes should avoid excessive dynamic valgus of the knee, always aiming for the "knee-over-toe position".

Proper rehabilitation of the index injury. The strong association observed between previous injuries, reduced muscle- and joint-specific function, and the risk for recurrent injuries suggests that secondary prevention of re-injury should be emphasized. It is of major importance to identify players with previous injuries, impaired neuromuscular control, and functional deficits to provide optimal treatment and to prevent further injuries. As is true for all injuries, it is important to provide an appropriate rehabilitation programme and enough time to allow the athlete to become symptom-free before returning to play (Hägglund et al., 2006; Myklebust & Bahr, 2005; Steffen et al., 2008a). An athlete who is not able to train without pain or other symptoms from a particular body part should be advised to undergo rehabilitation and restrict participation in competitions, as this probably will increase the risk for a new injury. Hägglund and colleagues (Hägglund, Waldén, & Ekstrand, 2007) have developed a 10-step rehabilitation programme that serves as return-to-play guidelines for soccer players, which has been shown to be effective in preventing re-injury.

Start early and identify athletes at risk. One goal in sports injury prevention is to teach athletes less vulnerable movement patterns, which may be easier to accomplish with young athletes who have not yet established their basic motion patterns. We therefore suggest that programmes to improve basic movement skills and strength, awareness, and neuromuscular control of static and dynamic movements be implemented in physical education curricula in schools and in youth sports clubs.

Implementation, establishment of routines, and maintenance. How much risk is reduced depends on compliance with the exercise programme (Soligard et al., 2008), as the compliance of coaches and athletes with injury prevention training is a challenge. It may be difficult to motivate coaches and players to follow such exercise programmes merely to prevent injuries, unless there is a direct performance benefit as well. However, it should be emphasized that improved performance will result when team members are free of injury and able to train and compete. Moreover, many of the elements included in evidence-based injury prevention exercise programmes also result in improved fitness (Mjølsnes et al., 2004; Myer, Ford, Palumbo, & Hewett, 2005).

Nevertheless, there is a limit to how much time teams and coaches are willing to spend on exercise programmes to prevent injury. For youth and adolescent athletes, who typically practise 2–4 times a week, it is not realistic to expect them to spend a similar amount of time on injury prevention exercises, even if they were shown to improve performance.

In our opinion, to successfully implement injury prevention exercises in the training programme of youth and adolescents on a consistent basis, the injury prevention exercise protocol must be well accepted by coaches and athletes. The duration of the programme should not exceed 20 min per session, and preferably be designed to replace the usual warm-up exercises. Based on previous research, such prevention programmes should include at least 15 training sessions during the first 6–8 weeks of training, preferably in the pre-season period (Hewett et al., 2006b; Myklebust et al., 2003; Olsen et al., 2005; Soligard et al., 2008; Steffen et al., 2008b). Further evidence is needed to determine whether a pre-season examination, such as a drop-jump or single-leg squad test, can be used to identify athletes at higher risk of injury (e.g. poor knee control). To succeed, injury prevention habits and training must be maintained throughout the season, which means that increasing difficulty, variation, and sport-specific adjustments of the exercises are needed to keep athletes motivated.

Coach education. The coach plays a key role in the successful implementation of injury prevention methods, such as exercise programmes in warm-up routines. To this end, coaches must understand the principles behind successful injury prevention exercise programmes and how to deliver them optimally to ensure high compliance. This goal can only be achieved if injury prevention becomes an integrated part of education programmes for coaches at all levels. If efficacious interventions are not widely adopted, complied with, and sustained as ongoing practice, then it is very unlikely that any significant health impact will be seen (Finch & Donaldson, 2009).

Injury prevention policy

The recommendations stated in the previous paragraphs all relate to those preventive strategies directly involved in the well-being of the athlete. The uptake of efficacious preventive measures by athletes, coaches, therapists, and referees is likely to have the most direct effect on injury prevention. Nevertheless, an equally important role in the health of an athlete is that of sport governing bodies and their policies. When a sport governing body includes specific injury prevention strategies as part of its policy, clubs and coaches are more likely to comply and adopt these in their regular routine. Negligence on the part of a sporting organization to promote injury prevention as part of their policies can be considered a "behavioural" factor in injury risk.

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