REVIEW

Risk factors for lower extremity injury: a review of the literature

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Prospective studies on risk factors for lower extremity injury are reviewed. Many intrinsic and extrinsic risk factors have been implicated; however, there is little agreement with respect to the findings. Future prospective studies are needed using sufficient sample sizes of males and females, including collection of exposure data, and using established methods for identifying and classifying injury severity to conclusively determine addtional risk factors for lower extremity injury.

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Numerous injuries occur each year caused by sport, resulting in decreased physical activity and work time lost in addition to substantial medical costs. World wide, the cost of sports injuries has been estimated at $1 billion annually.[1] Kraus and Conroy[2] estimated that 3–5 million injuries occur annually among competitive and recreational athletes in the United States alone. According to the National Collegiate Athletic Association injury surveillance system for 2000–2001, the most common injury sites were the ankle, knee, and lower leg among collegiate soccer, field hockey, basketball, and lacrosse athletes.[3] The most common injury types were muscle strains, ligament sprains, and contusions.

Prevention and intervention have become focal points for researchers and clinicians. Before these types of studies can be used, the risk factors for injury must be clearly established. Many injury risk factors, both extrinsic (those outside of the body) and intrinsic (those from within the body), have been suggested.[4] Extrinsic risk factors include level of competition, skill level, shoe type, use of ankle tape or brace, and playing surface. Intrinsic risk factors include age, sex, previous injury and inadequate rehabilitation, aerobic fitness, body size, limb dominance, flexibility, limb girth, muscle strength, imbalance and reaction time, postural stability, anatomical alignment, and foot morphology.[5]

The purpose of this paper is to provide a comprehensive review of the literature with regard to extrinsic and intrinsic risk factors for ankle, knee, leg, and foot injury. Retrospective and case-control studies are prone to bias because this approach cannot accurately characterise the multiple variables that must be evaluated in a population of athletes at risk of suffering a lower extremity injury. For example, exposure data can only be obtained through a prospective approach, and variables such as baseline strength or joint laxity cannot be determined after an injury has occurred. To predict injury, studies must measure potential risk factors in subjects before the occurrence of injury.

The studies included investigated risk factors among athletes and military recruits for ankle, knee, lower extremity, or all injuries as a group in which most occurred in the lower extremity. Studies were included if they were based on a clearly articulated hypothesis designed to determine the relation between proposed risk factors and injury, and if they were based on a prospective design using time to injury as an outcome measure or comparing potential risk factors between injured and uninjured groups. A thorough search of all important and relevant sources was performed through Medline and the Cochrane register. As numerous studies investigate multiple risk factors simultaneously, detailed methodology is provided only in the initial reference to a study.

EXTRINSIC RISK FACTORS

Level of competition

There is general agreement among researchers that injury incidence is greater during competition than in training sessions. Seil *et al*[6] performed a prospective study of European handball injuries in 186 men and found that injury incidence during competition was 24 times greater than in practice. An injury was defined as any incident that resulted in absence from at least one practice or game. Over half (54%) of all injuries occurred in the lower extremity, and the knee was the most commonly injured anatomical region.

Likewise, in a prospective study of 598 high school American football players, Prager *et al*[7] found a greater injury risk during games than in practice. Some 53% of all injuries occurred in games and scrimmages, and another 28% occurred in contact drills, compared with 19% in warm up and non-contact drills. In this study, an injury was defined as an incident that resulted in a loss of at least 48 hours of participation time. Some 59% of injuries occurred in the lower extremity, with the knee, ankle, and thigh being the most common injury sites.

Messina *et al*[8] found a greater number of injuries during games than in practice in a prospective study of 1863 male and female high school basketball athletes. A reportable injury

Abbreviations: IR, incidence rate; RR, relative risk; ACL, anterior cruciate ligament; OR, odds ratio; CI, confidence interval; ROM, range of motion; BMI, body mass index; NWI, notch width index was one that resulted in any time loss from participation, an incident that necessitated a consultation with a doctor, or one that involved the head or face. The ankle and knee were the most commonly injured body parts in both boys and girls.

Nielsen and Yde[9] found that 60.5% of injuries were sustained in games compared with practice in a study of 123 male Danish soccer players. An injury was defined as an incident that caused a player to miss at least one day of participation. Some 84% of all injuries occurred in the lower extremity, with the ankle being the most commonly injured body part. Similarly, Ekstrand *et al*[10] found a significantly greater injury incidence during matches (two thirds of traumatic injuries) than practice (one third of traumatic injuries) in a study of 180 male soccer players. An injury was defined as an incident that caused the player to miss the following practice or game, and 88% of all injuries were sustained in the lower extremity. Likewise, in a study of lower extremity injury in 146 female soccer players, Soderman *et al*[11] found an increased incidence (incidence rate (IR) = 10.0/1000 hours) of traumatic injury—for example, ligament sprains, contusions, and muscle strains—during games compared with practice (IR = 1.3/1000 hours). An injury was defined as an incident that caused absence from sport for at least one practice or game. The most common injuries were ankle sprains, hamstring strains, shin splints, knee contusions, Achilles tendinitis, and anterior knee pain.

Stuart and Smith[12] performed a three year prospective study of incidence and type of injuries among junior A ice hockey athletes (17–20 years of age) and found injury rates in games to be 25 times those in practice. The sample size and sex distribution were not presented. An injury was defined as an event that caused a player to miss a game or practice for a 24 hour period and required a consultation with the team doctor. The most common injuries were strains, lacerations, contusions, and sprains.

In a study of mechanism and incidence of acute volleyball injuries in 233 athletes, Bahr and Bahr[13] found an increased incidence of all injuries during competition for men, but no difference for women. An injury was registered if it resulted in absence of one or more days of competition or practice. Over half (54%) of all injuries sustained were ankle sprains.

Myklebust *et al*[14] performed a prospective cohort study of anterior cruciate ligament (ACL) injuries in 24 elite European handball teams and found that injury incidence during competition was 30 times greater than in practice. All ACL injuries were tears requiring surgical reconstruction and were verified through arthroscopic visualisation.

One study was found that analysed injury incidence related to the portion of the season. In a prospective study of recreational sports (Australian football, field hockey, basketball, and netball) injuries, Stevenson *et al*[15] found that incidence of injuries to the lower extremity or back was greatest in the first four weeks of the season. An injury was defined as an incident that resulted in any decrease in activity level, the need for advice or treatment, or adverse economic or social effects. These findings indicate that there may be a training effect that reduces the incidence of injury later in the season.

There is general consensus in the literature that the incidence of injury is greater during competition than practice. This finding suggests that athletes may be more prone to aggressive, risk taking behaviours during competition, which may in turn increase the potential for injury.

Skill level

Several studies have analysed the relation between skill level and injury; however, the findings are contradictory. In a study of the association between age, skill level, and injury in 264 male soccer players, Peterson *et al*[16] found that young players with low skill level had a twofold increased incidence of all injuries as a group compared with more skilled athletes. More than 79% of all injuries were sustained in the lower extremity, and more than half of all injuries were sustained to the knee, ankle, and lumbar spine. Similarly, in a study of factors related to severe injury in 398 male soccer players, Chomiak *et al*[17] reported that athletes in lower skill level groups had a twofold increase in incidence of all severe injuries as a group compared with the higher skill level groups. A severe injury was defined as one resulting in complaints lasting more than four weeks, absence from sport for four or more weeks, or an association with serious damage to the musculoskeletal system (fracture, dislocation, or damage to the visceral system). The knee and ankle were the most commonly injured body parts, and 74.2% of all injuries were sustained in the lower extremity.

Conversely, in a study of risk factors for lower extremity and back injury in 72 female netball athletes, Hopper *et al*[18] reported that athletes with the highest skill level were more likely to incur injury (54% of highest skill level) than less skilled athletes (19% of all other levels). The most common injury site was the ankle.

Hosea *et al*[19] found a more than twofold increased incidence of ankle injury at the collegiate level (presumably high skill level) compared with high school (low skill level) in 11 780 male and female basketball athletes.

With regard to skill level, two studies[16 17] have shown that athletes in low skill level groups are at increased risk of suffering injury, and two[18 19] reported that athletes in high skill level groups are at increased risk of suffering injury. It is difficult, however, to compare the results of these studies as they investigated different sports and therefore probably have diverse criteria for grouping skill levels. In addition, less skilled athletes may not compete for as long as those in higher skill level groups. Therefore, depending on the methodology used, low skill level groups may have the same number of injuries as higher skill level groups, but show a higher incidence rate based on less exposure. Alternatively, higher skill level groups may play at a more aggressive intensity than lower skill levels thereby increasing the risk of injury.

Shoe type

The association between shoe type and ankle injury is controversial. In a prospective study of ankle injury risk factors in 390 male military recruits, Milgrom *et al*[20] found no difference in ankle injury incidence between a group wearing combat boots during basic training compared with those wearing three quarter height basketball shoes. Likewise, Barrett *et al*[21] found no relation between three shoe types (low top, high top, and high top with inflatable chamber) and ankle sprain in 622 basketball athletes. However, they stated that the low injury rate may have been responsible for inadequate statistical power thereby affecting the results.

Conversely, McKay *et al*[22] found a more than fourfold increase in the incidence of ankle injury among elite and recreational basketball players wearing shoes with air cells in the heels compared with those wearing basketball shoes without air cells. An ankle injury was defined as an incident in which the player perceived that bodily harm caused stoppage of play, player substitution, or a display of disability. The authors stated that the increase in ankle injury incidence in shoes with air cells may be explained by decreased rearfoot stability.

One prospective study investigated the relation between cleat design and the incidence of ACL tears in 3119 high school American football athletes participating on natural turf. Lambson *et al*[23] reported significantly more ACL tears in athletes wearing edge cleat designs with longer irregular cleats positioned at the periphery of the shoe and smaller pointed cleats positioned interiorly (n = 38, IR = 0.017) than in athletes wearing other cleat types, including flat, screw in, and pivot disk designs (n = 4, IR = 0.005). An increased shoe to surface torsional resistance may have contributed to the increased risk of ACL tears in those athletes wearing the edge cleat design. All athletes had ACL tears that were verified through arthroscopic visualisation.

In summary, two studies[20 21] found no association between shoe type and injury, one [22] reported a higher incidence of ankle injury in basketball players wearing shoes with air cells in the heel, and one [23] reported an increased risk of sustaining ACL injury in footballers wearing edge style cleats compared with other cleat designs. Shoes, ankle tape, and braces have been used in attempts to prevent ankle sprains; however, the effect of shoe type on ankle injury has not received adequate investigation. Shoes offer external support, but factors other than support, including traction, limitation of joint mobility, and effects on proprioceptive input also need to be evaluated in future studies.[24]

Ankle bracing

Several studies have investigated the use of ankle braces to reduce the incidence of ankle sprains. In a prospective, randomised study of ankle brace use in 1601 military recruits playing intramural basketball, Sitler *et al*[25] found that the unbraced control group sustained more than a threefold incidence of ankle ligamentous injuries compared with the braced group. Likewise, Surve *et al*[26] studied the effect of bracing on the occurrence of ankle sprains in 504 male soccer players and found that, in athletes with a history of injury, the unbraced control group sustained more ankle injuries (1.16/1000 playing hours) than the group wearing ankle braces (0.46/1000 playing hours). There was, however, no difference in the incidence of ankle sprain in athletes without previous injury between the unbraced control group and the braced group. Also, Tropp *et al*[27] performed an injury prevention study with three subject groups: one that wore ankle braces, one that underwent ankle proprioceptive disk training, and an unbraced control group. Both interventions reduced the incidence of ankle sprains compared with the control group: 17% of the unbraced controls sustained an ankle sprain compared with 5% of the group that underwent ankle disk training and 3% of the group that wore ankle braces.

Conversely, in the aforementioned study, McKay *et al*[22] found that the use of ankle tape or braces by elite and recreational basketball players was not related to the incidence of ankle injury; however, they pointed out that only a small subgroup wore ankle braces or used tape for support, suggesting that there may have been inadequate statistical power to conclusively determine the relation between the use of ankle tape/brace and ankle injury.

There is general agreement in the literature that the use of ankle tape or brace decreases the incidence of ankle injury. One explanation for the dramatic reduction in injuries is that the use of ankle tape or brace increases the kinesthetic awareness of ankle positioning and increases support to the ankle joint by limiting hindfoot motion, specifically inversion.[28] Only one study[22] found no difference in ankle injury among basketball players who used ankle tape or brace and those who did not; however, inadequate statistical power may have affected this finding. The association between the use of ankle tape or brace and knee injury is less clear.

Playing surface

Artificial turf has been implicated as an injury risk factor in two studies. In a study of National Football League athletes between 1980 and 1985, Powell[29] found that playing on artificial turf increased the incidence of knee and foot/ankle injuries. Tartan Turf had the highest injury incidence rate (IR = 2.36) followed by Super Turf (IR = 2.34) and Astro Turf (IR = 1.94) compared with grass (IR = 1.78). Likewise, Arnason *et al*[30] found more than a twofold increased incidence of injuries on artificial turf compared with grass or gravel in 84 elite male soccer athletes. An injury was defined as an event that caused absence from one or more games or practice sessions. Some 71% of all injuries were sprains, strains, and contusions. The ankle, hamstrings, and lower back were injured most often.

Two studies[29 30] have reported that there is an increased incidence of injury on artificial turf compared with grass and gravel; however, the effect of playing surface on injury should receive additional investigation. More injuries may be incurred on artificial turf than on other surfaces because of its stiffness and the increased frictional force at the shoe/surface interface.[31] Stiffness of a surface affects impact forces and can result in overload to tissues such as bone, cartilage, muscle, tendon, and ligament. Friction is necessary for rapid starting, stopping, cutting, and pivoting inherent in sports such as football and soccer; however, increased frictional force may contribute to the increased incidence of injury among athletes who play on artificial turf.

Table 1 presents a synthesis of extrinsic injury risk factors.

INTRINSIC RISK FACTORS

Age

Age has been shown to be a risk factor for many diseases—for example, osteoarthritis.[32 33] It seems reasonable that age would also be a risk factor for lower extremity injury, as older athletes typically have increased exposure over time within their at risk activity whereas younger athletes have less exposure. However, risk factor studies have yielded contradictory results on the effect of age on injury.

Increased injury incidence has been reported with increased age among soccer players,[17 34–36] Australian football players,[37] recreational athletes,[15] and military recruits.[38] Ostenberg and Roos[35] studied 123 female soccer players (age range 14–39 years), and found a significantly increased risk of overall injury in athletes older than 25 years (odds ratio (OR) = 3.7, 95% confidence interval (CI) = 1.4 to 10.0) in comparison with younger athletes. Some 80% of all injuries sustained were in the lower extremity, and the most common injury sites were the knee, foot, ankle, thigh, and back. In a study of risk factors for lower extremity muscle strains among Australian football players, Orchard[37] found that athletes older than 23 years were more likely to incur hamstring strains (OR = 1.34, 95% CI = 1.14 to 1.57) and calf strains (OR = 2.59, 95% CI = 1.75 to 3.83), but age was not associated with quadriceps strains. An injury was defined as an event that occurred during a game and caused the player to miss the following competition. A different finding may have resulted had injuries occurring in training sessions been considered in addition to games in this investigation.

Similarly, in a study of youth aged 6–17 years participating in a summer soccer camp, Backous *et al*[34] reported that injury risk doubled after the age of 14. Some 71% of all injuries were sustained in the lower extremity; the ankle was the most commonly injured anatomical site in both boys and girls, and quadriceps strains were most common in boys. Also, in the previously detailed study of recreational sports injuries among subjects aged 9–56 years, Stevenson *et al*[15] found that athletes aged 26–30 were at 55% increased risk of injury compared with athletes younger than 26 and older than 30 years.

Likewise, in an investigation of risk factors for all injuries as a group sustained during basic combat training in 1230 military recruits aged 17–35 years, Knapik *et al*[38] reported that men in the 25–35 age group were at significantly increased risk of sustaining an injury of any type, but age was not a risk factor for women. An injury was defined as an incident that resulted in damage to the body and necessitated a visit to a medical care provider. Injuries involving the lower extremity and back accounted for 83% of all injuries incurred by men and 87% of all female injuries.

In a study of injury incidence among indoor soccer players, Lindenfeld *et al*[36] reported that men older than 25 years

Table 1 Extrinsic risk factors for injury

Risk factor	Sport	Sex	Injuries studied	Study type	Effect of risk factor	Ref.
Level of competition	European team handball	m,f	ACL	PNRCS	Increased risk in games compared with practice	14
	European team handball	m	All	PRF	Increased risk in games compared with practice	6
	American football	n/a	All	PRF	Increased risk in games compared with practice	7
	Basketball	m,f	All	PRF	Increased risk in games compared with practice	8
	Soccer	m	All	EPI	Increased risk in games compared with practice	9
	Soccer	m	All	PRF	Increased risk in games compared with practice	10
	Ice hockey	m	All	EPI	Increased risk in games compared with practice	12
	Volleyball	m,f	All	PRF	Increased risk in games compared with practice for males; and no difference for females	13
	Australian football, field hockey, basketball, netball	m,f	Lower extremity, back	EPI	Incidence greatest in first 4 weeks compared with remainder of season	15
	Soccer	f	Lower extremity	PRF	Increased risk in games compared with practice	11
Skill level	Soccer	m	All	PRF	Increased incidence in less skilled players	16
	Soccer	m	All severe	PRF	Increased incidence in less skilled players	17
	Netball	f	Lower extremity, back	PRF	Increased incidence in more skilled players	18
	Basketball	m,f	Ankle	PRF	Increased incidence in college *v* high school	19
Shoe Type	Basketball	m,f	Ankle	PRF	Increased incidence with inflatable air cells in heels	22
	American football	n/a	ACL	PRF	Increased incidence with edge style cleats compared with other cleat designs	23
	Military training	m	Ankle	PRF	No difference between combat boots and basketball shoes	20
	Basketball	m,f	Ankle	RCT	No difference between low top, hi top, or hi top w/ air cell	21
Ankle Bracing	Military training, basketball	m,f	Knee and ankle	RCT	Fewer contact injuries among braced athletes; and no difference in non-contact injuries	25
	Soccer	m	Ankle	RCT	Fewer injuries among braced and exercise group compared with unbraced	27
	Soccer	m	Ankle	RCT	Fewer ankle injuries among braced athletes with previous injury; and no difference in ankle injury rates in athletes without previous injury	26
	Basketball	m,f	Ankle	PRF	No difference between braced, taped, unbraced athletes	22
Playing surface	Soccer	m	All	PRF	Increased incidence on turf compared with grass or gravel	30
	American football	m	Knee, foot/ankle	PRF	Increased incidence on turf compared with grass	29

ACL, Anterior cruciate ligament; EPI, epidemiological; PRF, prospective study of potential risk factors; RCT, randomised clinical trials; PNRCS, prospective non-randomised comparative study.

suffered the highest rate of all injuries considered as a group (IR = 7.9) compared with males in the age ranges 19–24 years (IR = 3.8), 16–18 years (IR = 4.9), 12–15 years (IR = 4.4), and younger than 12 years (IR = 2.8). For females, the highest rate of all injuries was in the 12–15 age range (IR = 6.3) compared with those less than 12 years (IR = 5.6), and those in the age ranges 16–18 years (IR = 4.6), 19–24 years (IR = 4.9), and older than 25 years (IR = 5.1). An injury was defined as any incident that caused a player to leave a game, required a stoppage in play by the referee or player, or resulted in the player requesting medical attention. The body parts most often injured were the ankle and knee.

Two studies were found that showed increased injury incidence at a younger age.[16 22] In the aforementioned risk factor study of all injuries as a group among male soccer players, Peterson *et al*[16] found an increased risk of injury in young (aged 14–16 years) athletes compared with those in the 16–18 age range. Similarly, in a study of ankle injury risk factors among elite and recreational basketball players, McKay *et al*[22] reported that younger athletes (mean (SD) age 25.2 (6.6) years) were at increased risk of sustaining ankle injury compared with older athletes (mean (SD) age 28.0 (7.7) years).

Age was not found to be an injury risk factor among dancers,[39] female soccer players,[11] female netball players,[18] or track and field athletes.[40] Wiesler *et al*[39] investigated the incidence of lower limb injury in 148 dancers (age range 12–28 years) and found that age was not a risk factor for injury. Likewise, Soderman *et al*[11] did not find age to be a risk factor for injury in a study of female Swedish soccer players (mean (SD) age 20.6 (4.7) years). Similarly, in a study of risk factors for lower extremity and back injury in female netball players (mean (SD) age 20.6 (3.6) years), Hopper *et al*[18] found no association between age and injury. Also, in a prospective study of risk factors for stress fractures in 101 male and female track athletes (mean (SD) age 20.4 (2.1) years), Bennell *et al*[40] found no difference in age between athletes who incurred stress fractures and those who did not. Stress fractures were diagnosed on the basis of clinical examination and increased signal on bone scan and computed tomography scan. Most injuries were located in the tibia. In addition, Chomiak *et al*[17] found a similar incidence of severe injury among soccer athletes aged 14–41 years; however, injury type differed by age group. There was a trend toward more muscle strains, severe ligament ruptures, and meniscal tears with increasing age whereas there were fewer minor joint sprains, contusions, and spinal fractures among older athletes.

In conclusion, six studies[15 34–38] showed an increased incidence of injury in older athletes, two[16 22] found an increased incidence of injury in younger athletes, and five[11 17 18 39 40] found no association between age and injury. It is difficult to compare the findings of these studies because research methods differed in terms of the sports, age ranges, and types of injuries investigated. Furthermore, several of the aforementioned studies focused on a narrow age range, which may have made it difficult to observe the association between age and injury. Additional research is needed on larger age distributions.

Sex

It is well documented that female athletes incur substantially more knee injuries than male athletes, specifically ACL sprains.[14 41–50] In a study of ACL injuries among Norwegian handball players, Myklebust *et al*[14] found that women had a fivefold increased risk of sustaining ACL injuries compared with men. Likewise, Gwinn *et al*[42] evaluated the incidence of ACL injuries among male and female military recruits participating in intercollegiate sports, coed intramural sports, and military training and found a combined relative risk of 2.44 for women compared with men. Within intercollegiate sports, female soccer players were 9 times more likely to sustain an ACL tear than male soccer players; however, there were no significant differences in the relative risk between the sexes among basketball or rugby players. Within coed intramural sports, female soccer players were nearly 7 times more likely to sustain an ACL tear than male soccer players, but there were no significant differences in the relative risk between male and female basketball players. Finally, within military training, women had a relative risk of 9.74 compared with men. ACL injuries were defined as tears requiring surgical reconstruction and were confirmed arthroscopically.

The effect of sex on ankle specific injuries and lower extremity injuries as a group is less clear than the relation between sex and knee ligament injuries. Zelisko *et al*[50] found that female professional basketball athletes suffered 60% more injuries than men, with knee and thigh injuries being most common in the former. An injury was defined as an incident that was reported to and evaluated by an athletic trainer. The most common anatomical site injured among male and female athletes combined was the ankle. Likewise, Backous *et al*[34] performed a prospective study of youth soccer injuries and found a greater overall injury incidence for girls (10.6 injuries/1000 hours of exposure) than boys (7.3 injuries/1000 hours). Also, Knapik *et al*[38] found the incidence of all injuries for women to be twofold greater (IR = 1.16/100 person days of exposure) than for men (IR = 0.56/100 person days) in a study of military recruits during basic combat training. Similarly, Bell *et al*[51] investigated the effect of sex on injury rates among 861 military recruits during basic combat training. Women experienced twice as many injuries as men (relative risk (RR) =2.1, 95% CI = 1.78 to 2.5). Any injury that resulted in a visit to and evaluation by a medical provider was included. Hosea *et al*[19] investigated the incidence of ankle injury among high school and collegiate basketball athletes. Girls were at greater risk of sustaining minor grade I ankle sprains (RR = 1.26:1); however, no difference was found between boys and girls for the more severe grade II and III ankle sprains.

In contrast, several studies have found no significant differences in injury rates between male and female athletes. In a prospective study of ankle sprain incidence in 145 collegiate field hockey, soccer, and lacrosse athletes, Baumhauer *et al*[52] found no difference in the incidence of ankle sprains between men and women. In a similar study, Beynnon *et al*[53] found that the relative risk of ankle sprain among 118 collegiate field hockey, soccer, and lacrosse athletes was the same for men and women; however, the risk factors were different for the two sexes. In men, an increased talar tilt was a risk factor for ankle injury, whereas increased tibial varum and increased calcaneal eversion were risk factors for women. Likewise, in a prospective study of risk factors for stress fractures among male and female track athletes, Bennell *et al*[40] found no difference in injury rates between the two, but the risk factors differed. No predictors were found in men, and in women risk factors were age of menarche, bone mineral content, and calf girth. Wiesler *et al*[39] investigated the relation between ankle range of motion (ROM) and injury among dancers and found no difference in injury incidence between the sexes. Beachy *et al*[54] performed a prospective study of 14 318 high school athletes over an eight year period. Without considering football and wrestling, there were no differences in injury incidence between boys and girls. An injury was defined as any episode that required an evaluation by an athletic trainer. Some 70% of the most commonly injured sites were in the lower extremity.

One study was found that reported increased risk of specific injuries in association with sex. Lindenfeld *et al*[36] reported that the injury rate for all injuries as a group was similar for men (IR = 5.04) and women (IR = 5.03); however, the rate of ankle and knee specific injuries differed between men and women. Men had a threefold increased risk of sustaining ankle ligament injuries compared with women, whereas women had a threefold increased risk of sustaining knee ligament injuries compared with men.

Two studies were found in which male athletes had a slightly higher rate of injury. Messina *et al*[8] performed a prospective study of high school basketball athletes and found that the overall injury rate was higher among boys (0.56 injuries per season) than girls (0.49 injuries per season), and girls had a 60% greater incidence of knee injury than boys. Furthermore, the incidence of ACL injuries was 3.6 times higher in girls than boys. Likewise, Stevenson *et al*[15] found that males had a higher incidence of all injuries (IR = 19.0/1000 hours of exposure, 95% CI = 17.7 to 20.2) than females (IR = 13.6/1000 hours of exposure, 95% CI = 12.3 to 14.9) in a prospective study of athletes participating in recreational sports.

Seven studies[14 19 34 38 42 50 51] showed that female athletes had an increased incidence of injury, two[8 15] reported that male athletes showed an increased incidence of injury, five studies[39 40 52–54] found no association between sex and injury, and one[36] found that the rate of ankle and knee specific injuries differed between the sexes. Many explanations have been suggested for why female athletes suffer more serious knee injuries than male athletes, including anatomical, hormonal, and neuromuscular factors.[46] Although it is clear that female athletes are at increased risk of suffering ACL injuries, the relation between sex and other types of lower extremity injury is unclear. This may be explained by the variety of methods of injury evaluation, grading criteria, definitions of injury, statistical methods, and sports studied.

Phase of the menstrual cycle

A number of researchers have suggested that hormonal fluctuations associated with the menstrual cycle may be one explanation for the increased risk to women of sustaining ACL injury. In a prospective cohort study of ACL injuries in 24 elite handball teams, Myklebust *et al*[14] used self reported menstrual history from 17 female athletes who sustained ACL sprains, eight of whom used oral contraceptives, and nine reported regular menses. The menstrual cycle was set at 28 days for all athletes and separated into four distinct phases as follows: days 1–7, menstrual phase; days 8–14, follicular phase; days 15–21, early luteal phase; and days 22–28, luteal phase. Five of the ACL sprains occurred in the menstrual phase, two in the follicular phase, one in the early luteal phase, and nine in the late luteal phase. The results suggest that there may be an increased risk of suffering ACL sprains during the week before or after the start of the menstrual period. The results of this study are difficult to compare with others investigating the relation between phase of menstrual cycle and ACL injury because the methods used to characterise menstrual history were not reported, and the menstrual cycle phase at the time of injury was inferred on the basis of self reports, not confirmed through measurements of actual hormone levels.

One study was found that documented the phase of the menstrual cycle by saliva analysis of hormone levels collected within 72 hours of injury as well as self reported menstrual history. Slauterbeck *et al*[55] investigated the relation between ACL injury and the phase of menstrual cycle among 37 female athletes as follows: 21 subjects provided saliva samples to determine levels of oestrogen and progesterone and self reported menstrual history, 10 provided only saliva samples, and six provided only menstrual histories. Of the 37 athletes, 25 injured their ACLs during the follicular phase, one during the ovulatory phase, and 11 during the luteal phase of the menstrual cycle. Of the 37 women, six used oral contraceptives, and five of these athletes injured their ACLs during the follicular phase. The results of this study showed an increased risk during the follicular phase of the menstrual cycle, with a significantly greater number of ACL injuries occurring on days 1 and 2. These results are difficult to compare with similar studies because the authors did not report the criteria used to determine the menstrual cycle phase.

One study documented the phase of the menstrual cycle using hormone metabolite measurements based on urine samples. In a study of the effect of the menstrual cycle on ACL injuries in 65 female athletes, Wojtys *et al*[56] collected urine samples to determine the levels of oestrogen, progesterone, luteinising hormone, and creatinine. Two urine samples were collected: one within 24 hours of the injury and another within 24 hours of the first day of the athlete's next menstrual period. The authors separated the menstrual cycle into three distinct phases: days 1–9, follicular phase; days 10–14, ovulatory phase; and days 15–28, luteal phase. In women who were not taking oral contraceptives, significantly more ACL injuries occurred during the ovulatory phase. Furthermore, in women using oral contraceptives, there was a trend toward more ACL injuries during the ovulatory phase. This is the only study to date that has measured hormone levels at the time of injury as well as at the onset of the following menstrual period.

Three studies have investigated the relation between phase of menstrual cycle and ACL injury; however, the findings are contradictory. Two studies[14 55] found that the risk of sustaining an ACL injury is greater at or near the onset of menstruation, and one[56] reported that there is increased risk during the ovulatory phase for women not using oral contraceptives. If the phase of the menstrual cycle is a risk factor for ACL injury, it is unclear where, and by what mechanisms, the hormones are acting. Oestrogen and progesterone receptors have been identified on the rabbit ACL,[57 58] implying that these hormones may directly influence the structure and composition of the human ligament. It may be that cyclic changes in the biomechanical properties of the ACL combine with and amplify other risk factors resulting in compromises to proprioceptive feedback, neuromuscular control, or biomechanical loading. Additional research is needed that uses common time intervals to establish the menstrual phases, investigates subjects with different cycle lengths, measures actual hormone levels present in urine, saliva, or serum, and documents hormone levels at both the time of injury and the onset of the following menstrual period in order to more accurately determine the menstrual phase and cycle length in which the injury occurred.

Previous injury and inadequate rehabilitation

Injury not only compromises important static and dynamic stabilisers of the lower extremity, but may also be associated with deafferentiation of a joint. For example, disruption of the ACL not only creates an increase in anterior knee laxity, and may be associated with repeated episodes of giving way, but it also compromises a portion of neuroreceptors that innervate the joint and may result in worsened proprioception.[59] There is strong evidence that previous injury, especially when followed by inadequate rehabilitation, places an athlete at increased risk of suffering an injury to the ankle,[13 20 22 26 60] knee,[8] and all injuries as a group.[17 39]

In a study comparing ankle sprain incidence in those using a sport stirrup (brace) versus an unbraced control group, Surve *et al*[26] reported a significant increase in ankle injury rates among unbraced athletes with a previous ankle injury (IR = 0.86/1000 hours) compared with unbraced athletes with no history of injury (IR = 0.46/1000 hours).

One study was found that investigated the association between injury history and lower extremity muscle strains among Australian football players. Orchard[37] reported that an injury sustained within the last eight weeks increased the risk of sustaining a muscle strain to the same location for the hamstrings (RR = 6.33), quadriceps (RR = 15.61), and calf muscles (RR = 8.94). Likewise, injuries sustained outside of an eight week time interval resulted in an increased risk of sustaining muscle strains at the same location for the hamstrings (RR = 2.42), quadriceps (RR = 3.67), and calf (RR = 4.28).

Several studies were found that reported no relation between previous injury and ankle injury rates. Baumhauer *et al*[52] did not find an increased risk of ankle sprain among collegiate athletes who had previously incurred a mild grade I sprain. Those who had incurred a more severe grade II or III ankle sprain were excluded from participation; therefore the effect of severe ankle injury on the risk of re-injury was not studied. In a study of the relation between postural sway (balance) and ankle injury in 127 male soccer players, Tropp *et al*[61] found those with a history of ankle injury did not show an increased risk of ankle sprain. Barrett *et al*[21] did not find a history of ankle sprain to be a predictor of re-injury to the same ankle in a randomised study of the effect of high top versus low top basketball shoes.

Several reasons have been offered that explain the increased risk of incurring the same type of injury in subjects with an injury history. These include proprioceptive defects (functional instability), muscle strength impairment and imbalance, persistent ligamentous laxity (mechanical instability), diminished muscle flexibility and joint movement, and the presence of localised scar tissue, which produces discomfort.[28] The disparity between studies with regard to the effects of previous ankle injury on future occurrence may be related to the definition of what constitutes an injury, differing assessment techniques, or quality of rehabilitation.

Several studies were found that isolated inadequate rehabilitation or premature return to play as injury risk factors. In a prospective study of overall injury incidence and mechanism among male soccer players, Ekstrand and Gillquist[62] found athletes who were improperly rehabilitated, or were not ready to return to a pre-injury level of competition, to be at increased risk of suffering injury. In 32 (25.8%) of the 124 players who suffered a minor injury, a major injury was subsequently sustained within two months, 13 (10.5%) of which were of the same type and location. Injuries were categorised on the basis of duration of absence from practice; a minor injury resulted in absence from practice for less than one week, whereas a major injury resulted in absence from practice for more than one month. Similarly, Chomiak *et al*[17] reported that inadequate rehabilitation was a risk factor for severe injury among male soccer players. Nearly one quarter (n = 23, 24%) of the 97 players who sustained injury had previously injured the same body part, seven of whom had done so within the past three months. Furthermore, in a study of risk factors for ACL injury in 1643 Australian football players, Orchard *et al*[63] found an increased risk of ACL injury among those athletes who underwent an ACL reconstruction on the ipsilateral side within the previous 12 months (RR = 11.33, 95% CI = 4.02 to 31.91). This finding suggests that the athletes were not physically ready to return to their former level of competition. An increased risk of ACL injury was also found in those who underwent ACL reconstruction within a period greater than 12 months (RR = 4.44, 95% CI = 2.46 to 8.01). Seven (41%) of these 17 ACL injuries were to the ipsilateral side, and 10 (59%) were to the contralateral side.

Seven studies[8 13 17 20 22 26 39] have found previous injury to be a risk factor for sustaining subsequent injury, and three[21 52 61] reported no association between previous injury and subsequent injury. There is strong evidence in the literature that previous injury in conjunction with inadequate rehabilitation is a risk factor for re-injury of the same type and location. Previous injury may lead to an increased risk of sustaining future injury by contributing to muscular weakness and imbalance, impairment of ligaments, and fear of re-injury that could cause the athlete to use altered muscle recruitment strategies and lose focus causing an inability to maintain attention to appropriate visual cues.

Aerobic fitness

It seems reasonable that the level of aerobic fitness would be a risk factor for injury because, once fatigued, most athletes alter their muscle recruitment patterns. This altered recruitment pattern, in turn, may alter the distribution of forces acting on the articular, ligamentous, and muscular structures. However, the relation between aerobic fitness and injury is unclear, and this may be explained in part by the different techniques used to quantify aerobic fitness.

Milgrom *et al*[20] measured fitness in terms of 2 km run times and number of chin ups and sit ups completed, and found no significant difference among military recruits who sustained lateral ankle sprains and those who did not. Correspondingly, in an injury risk factor study of female soccer players, Ostenberg and Roos[35] quantified aerobic fitness using 20 m shuttle run times, vertical jump height, one leg hop distance, and a 30 second square hop test and found no difference in fitness measures between those who sustained injury and those who did not.

Several lower extremity and general injury studies have shown a relation between aerobic fitness and injury. In a study of factors for severe injury in male soccer players, Chomiak *et al*[17] found poor physical condition to be a risk factor for all injuries as a group. Those athletes who sustained injuries had slower reaction times to an optical signal after a 12 minute run.[64] Knapik *et al*[38] found that risk factors for all injuries as a group among male and female military recruits included fewer numbers of push ups completed, slower run times, lower peak V_{O_2}, and smoking cigarettes. Self reported poor condition before basic training, quantified in exercise bouts per week, was a risk factor for men, but not for women. In a study of the relation between sex and injury among military trainees, Bell *et al*[51] found that aerobic fitness, quantified in 1 mile run times, was a predictor of overall injury in both men and women. There was a significant increase in injury incidence among subjects with slower run times. The slowest runners were at 3.5 times greater risk of incurring injury than the fastest runners. Similarly, in an intrinsic risk factor study of male and female military recruits followed during basic combat training, Jones *et al*[65] found that women with slower 1 mile run times were twice as likely to sustain lower extremity injury as the fastest female runners. Men who performed fewer push ups were at a fivefold increased risk of sustaining lower extremity injury compared with those who performed the most push ups.

In contrast, Hopper *et al*[18] reported that female netball players who incurred any injury had increased vertical jump height, and increased work and peak power during a modified Wingate test compared with those who did not sustain injury.

An association between measures of aerobic fitness and injury was shown in five studies,[17 18 38 51 65] and two[20 35] found no association. Diminished aerobic fitness may cause fatigue leading to a reduction in the protective effect of musculature on skeletal structures. Unfortunately, these studies used different methods to characterise aerobic fitness, making it difficult to compare the findings and necessitating additional research that uses uniform methodology.

Body size

Body size has been analysed in risk factor studies in a number of ways including height and weight,[18 53] lean muscle mass, body fat content, body mass index (BMI),[34 35 38] Quetelet index,[7] and mass moment of inertia.[20] These variables have been considered as risk factors for injury because an increase in any one produces a proportional increase in the forces that articular, ligamentous, and muscular structures must resist; however, the relation between body size and injury is unclear.

Jones *et al*[65] found low and high BMI and high body fat content for men, and shorter height for women to be risk factors for sustaining lower extremity injury among military recruits. Men in the lowest and highest quartiles for BMI had a threefold increase in the incidence of all lower extremity injuries compared with the middle 50% of male recruits. Men in the upper quartile for body fat, measured by a sum of four skinfolds, had nearly twice the incidence of injury compared with the remaining 75% of men. Women in the lowest quartile for height were nearly twice as likely to sustain lower extremity injury as the remaining 75% of female recruits. Backous *et al*[34] reported an increased incidence of injury among boys taller than 165 cm in a prospective study of youth soccer players; however, body size was not a risk factor for girls. Orchard[37] reported an increased incidence of quadriceps injury (RR = 1.48) among Australian football players of height less than 182 cm compared with taller athletes; however, height was not associated with hamstring or calf muscle strains. There was no association between weight and lower extremity muscle strains. Milgrom *et al*[20] found that male military recruits with a larger mass moment of inertia (weight × height^2) had a significantly increased risk of sustaining a lateral ankle sprain.

Conversely, a number of studies have reported no association between body size and injury. Knapik *et al*[38] did not find height, weight, or BMI to be risk factors for all injuries as a group among female and male military recruits. Baumhauer *et al*[52] reported no effect of height or weight on the incidence of ankle injury among collegiate athletes participating in soccer, field hockey, and lacrosse. In a similar population of athletes, Beynnon *et al*[53] reported no association between height or weight and the incidence of ankle injury. Likewise, McKay *et al*[22] did not find a significant difference in height or weight among elite and recreational basketball players who incurred ankle injury and those who did not. Similarly, Bennell *et al*[40] found no difference in height, weight, total lean mass, or body fat among male and female track athletes who sustained stress fractures compared with those who did not. Furthermore, Ostenberg and Roos[35] did not find BMI to be a risk factor for all injuries considered as a group among female soccer athletes. Wiesler *et al*[39] did not find BMI to be a risk factor for lower extremity injury among dancers. In a study of general injury risk factors in 136 physical education students participating in intramural sports, Twellaar *et al*[66] found no significant differences in terms of height, weight, or BMI between those who sustained injury and those who did not. An injury was defined as any physical discomfort that resulted in diminished activity, and the legs were involved in 66% of all injuries. The most common injuries were sprains, contusions, and myalgia. In addition, Prager *et al*[7] found no association between Quetelet index ((weight/height) × 100) and injury among high school football players.

Body size has been implicated as an injury risk factor in four studies,[20 34 37 65] whereas no association between body size and injury was found in nine.[7 22 35 38–40 52 53 66] The aforementioned studies used many different techniques to represent body size making it difficult to compare the findings and conclusively determine the association between body size and injury. Additional investigations that use a common outcome measure to represent body size are needed.

Limb dominance

In certain sports, the dominant leg may be at increased risk of injury because it is preferentially used for kicking, pushing off, jumping, or landing. However, the association between limb dominance and injury is controversial. Several risk factor studies have reported that limb dominance has an effect on injury. Baumhauer *et al*[52] reported that left leg dominant collegiate athletes participating in soccer, field hockey, and lacrosse were more likely to incur ankle sprains than right leg dominant athletes. Ekstrand and Gillquist[67] found that the dominant leg sustained significantly more ankle injuries (92.3%) than the non-dominant side in male soccer players, but there was no effect of limb dominance in those who sustained muscle strains. Chomiak *et al*[17] reported no effect of limb dominance on severe ankle and non-contact knee injuries in male soccer players; however, the dominant leg incurred significantly more contact knee injuries. Orchard[37] reported that quadriceps strains were more commonly sustained by the dominant leg (RR = 2.13, 95% CI = 1.59 to 2.86) than the non-dominant side in female netball players, but there was no association between limb dominance and injury of the hamstrings or calf muscles.

Beynnon *et al*[53] found no influence of limb dominance on ankle sprains in the aforementioned study of collegiate soccer, field hockey, and lacrosse athletes. Likewise, Surve *et al*[26] found no effect of limb dominance on the incidence of ankle sprain in a study of the effect of the use of ankle braces on the occurrence of ankle sprains. Furthermore, in a study of injuries in 186 male European handball players, Seil *et al*[6] reported no association between limb dominance and lower extremity injury.

Four studies[17 37 52 67] have reported an association between limb dominance and injury. Of these, one study found that left leg dominant athletes were more likely to sustain ankle injury, one reported that the dominant leg sustained more non-contact knee injuries, one found an increased incidence of ankle injury on the dominant side, and one reported an increased incidence of quadriceps strains on the dominant leg. In contrast, three studies[6 26 53] reported no association between limb dominance and injury. Therefore, the relation between limb dominance and injury remains unclear.

Flexibility

The flexibility of a joint is determined by the geometry of the articular surfaces and by muscle, tendon, ligament, and joint capsule laxity.[68] Conventional wisdom asserts that there is a relation between increased flexibility and decreased incidence of injury; however, the effect of measures of flexibility, which includes generalised and joint specific laxity, muscle tightness, and ROM, on injury is controversial.

Generalised joint laxity

The relation between generalised joint laxity and injury is unclear. Generalised joint laxity has been shown to be a risk factor for all injuries considered as a group among female soccer players.[11 35] In a prospective study of 123 female soccer athletes, Ostenberg and Roos[35] found that athletes who scored 4 and above (on a scale of 0–9, with 9 being the greatest laxity) on the Beighton scale[69] were at a fivefold increased risk of incurring injury compared with those with lower generalised joint laxity scores. Soderman *et al*[11] used a similar method of measuring generalised joint laxity and determined that athletes with increased generalised joint laxity (scores of 5 or more) were at 3.1 times increased risk of traumatic leg injuries (95% CI = 1.19 to 8.01) in a prospective study of leg injury risk factors among female soccer athletes; however, increased laxity was not a risk factor for overuse leg injury—for example, pain, medial tibial stress syndrome, and synovitis.

Conversely, a number of studies have reported no association between generalised joint laxity and injury. Godshall[70] found no relation between generalised joint laxity and injury in an eight year study of male high school football players. Two ankle specific studies[52 53] did not find generalised joint laxity to be an injury risk factor for ankle sprains among collegiate soccer, field hockey, and lacrosse athletes. Likewise, Hopper *et al*[18] reported no association between generalised joint laxity and lower extremity and back injury among female netball players. Krivickas and Feinberg[68] performed a prospective study of the relation between muscle tightness, ligament laxity, and lower extremity injury in 201 college athletes. No relation between generalised joint laxity and lower extremity injury was found for women; however, for men there was a significant relation between decreased generalised joint laxity (95% CI = 0.2 to 1.5 on Beighton scale) and ankle injury.

Concerning the relation between generalised joint laxity and injury, two studies[11 35] reported a greater incidence of injury among women with increased generalised joint laxity, one[68] found a greater incidence of injury among men with decreased generalised joint laxity values, and four studies[18 52 53 70] showed no association. It is possible that sex plays a role in the association between generalised joint laxity and injury. Generalised joint laxity is a composite measure of overall flexibility—for example, fingers, wrists, knees, elbows, and hip/spine complex—in contrast with joint specific laxity, which may change as a result of injury.[68] It is difficult, however, to develop an approach that examines joint specific laxity without the influence of muscle contraction and stiffness and vice versa. This, combined with the fact that sports with different inherent risks and dissimilar male to female ratios have been studied, makes the findings of these studies difficult to compare.

Ankle and knee joint laxity

The relation between ankle laxity and ankle injury is unclear; however, several studies have shown an association between knee laxity and knee injury.

In a study of elite male soccer athletes, Arnason *et al*[30] found no difference in incidence of ankle injury in those with increased laxity based on the anterior drawer and talar tilt tests versus those with normal laxity. There was, however, a significant increase in knee injuries among those with increased medial joint laxity based on clinical evaluation. Likewise, Ekstrand and Gillquist[67] found male soccer athletes with increased knee laxity, based on varus/valgus and anterior/posterior clinical examinations, to be at significantly increased risk of injury. Furthermore, Chomiak *et al*[17] found increased knee laxity, based on the anterior drawer, Lachman, valgus and varus stress tests, to be a risk factor for knee and ankle injury among soccer players. Increased laxity was found in seven out of 29 subjects (24%) who sustained knee injury. Half of non-contact ankle injuries and 15% of contact injuries were sustained in subjects who showed increased ankle laxity based on anterior drawer and talar tilt tests. Beynnon *et al*[53] reported an association between increased talar tilt and increased incidence of ankle injury among collegiate male soccer and lacrosse athletes; however, no association was found among women who participated in the same sports. Similarly, Glick *et al*[71] performed inversion stress *x* ray examinations of 396 ankles in 198 intercollegiate footballers and found an association between increased talar tilt and injury. There were 42 ankle sprains; 19% (12 of 62) were sustained in those with increased talar tilt, and 9% (30 of 334) were sustained in those with an insignificant talar tilt.

Conversely, other studies have not found a link between ankle laxity and injury using the anterior drawer and talar tilt tests. Barrett *et al*[21] reported no association between ankle laxity and ankle injury in basketball athletes. Baumhauer *et al*[52] reported no association between ankle laxity and ankle injury among collegiate soccer, field hockey, and lacrosse athletes.

With regard to ankle and knee joint laxity, five[17 30 53 67 71] studies have reported an increased incidence of injury in subjects with increased joint laxity, and two[21 52] reported no association. The confounding findings of the aforementioned studies may derive from the clinical examinations used to assess joint laxity and the inherent potential for diminished interrater reliability.[72] A more reliable and less subjective method for measuring joint laxity would be to use radiographically based stress measurements. Unfortunately, this is not commonly used because of the cost and increased risk associated with these techniques.

Muscle tightness

Several studies have shown a relation between muscle tightness and injury. Krivickas and Feinberg[68] introduced a new scale for assessing muscle tightness of hip flexors, hamstrings, quadriceps, and gastrocnemius and applied it in a prospective study of lower extremity injury among collegiate athletes. No relation between muscle tightness and injury was found for women; however, for men, there was a significant relation between increased muscle tightness and incidence of lower extremity injury in general and, more specifically, between increased iliopsoas tightness and overuse knee injury. Similarly, Knapik *et al*[38] found male military recruits with abnormally high and low levels of hamstring flexibility, measured by a sit and reach test, to be twice as likely to incur any type of injury as those with average flexibility. Flexibility was not a risk factor in female military recruits. Kaufman *et al*[73] investigated the relation between foot structure and ROM and lower extremity musculoskeletal overuse injuries among military recruits. Increased tightness of the gastrocnemius was found to be a risk factor for Achilles tendinitis (RR = 3.57, 95% CI = 1.01 to 12.68). McKay *et al*[22] performed an ankle injury risk factor study on elite and recreational basketball players and found that those athletes who did not stretch during warm up were at a significantly increased risk (OR = 2.62, 95% CI = 1.01 to 6.34) of injury compared with those who did stretch.

One study did not show a link between muscle tightness and injury. In a study of elite male soccer athletes, Arnason *et al*[30] found no difference in muscle tightness between those who suffered muscle strains and those who did not.

In summary, four studies[22 38 68 73] have reported an association between muscle tightness and injury, whereas one[30] did not find an association between muscle tightness and injury. The findings of general injury studies and studies of the influence of muscle tightness on ligament sprains are confounding because of research designs using various methods of measuring muscle tightness, diverse injury types, and a variety of sports with different inherent risks.

Range of motion

The literature is divided about the relation between ROM and lower extremity, ankle, or knee injury. There is some evidence that ROM is an injury risk factor for all injuries as a group,[11] ankle injury,[53] and lower extremity injury.[73] Soderman *et al*[11] found knee hyperextension greater than 10° to be a risk factor for lower extremity injury in female soccer players (OR = 2.50, 95% CI = 1.11 to 5.61); however, ankle dorsiflexion ROM and hamstring flexibility were not risk factors. Side to side differences in ankle dorsiflexion ROM (OR = 7.06) and hamstring flexibility (OR = 3.56) were found to be risk factors for overuse leg injury. Beynnon *et al*[53] showed that increased calcaneal eversion motion was a risk factor for ankle sprains in female collegiate athletes, but not for male athletes. Kaufman *et al*[73] found that increased hindfoot inversion was a risk factor for Achilles tendinitis (RR = 2.79, 95% CI = 0.91 to 8.55), but ankle and hindfoot motion were not risk factors for lower extremity stress fractures in military recruits.

Several studies have reported no relation between ROM and lower extremity injury. Twellaar *et al*[66] found no significant differences in terms of ROM about the ankle, hip, and knee between physical education students who sustained lower extremity injuries and those who did not. In a study of lower extremity injury among dancers, Wiesler *et al*[39] did not find a relation between ankle ROM and injury. Likewise, Barrett *et al*[24] reported no relation between plantar and dorsiflexion ROM and ankle injury among basketball players. In addition, Milgrom *et al*[20] found no relation between hip internal and external rotation in male infantry recruits who sustained lateral ankle sprains compared with those who did not.

In conclusion, three studies[11 53 73] reported a relation between increased joint ROM and injury, whereas four[20 24 39 66] reported no association. ROM measurements, similar to joint laxity assessments, have an inherent potential for diminished interrater reliability, and therefore may yield contradictory results. Elveru *et al*[74] performed a reliability study of ankle goniometric measurements. Intratester reliability (ICC) for ankle and subtalar joint measures ranged from 0.74 to 0.90. Intertester reliability (ICC), however, was 0.25 for measuring subtalar neutral, 0.32 for inversion, and 0.17 for eversion. Ankle dorsiflexion (ICC = 0.50) and plantar flexion (ICC = 0.72) measures were more reliable between testers. In addition, the studies reviewed in this paper quantified ROM about different joints in various planes, investigated numerous sports, and used diverse statistical methods, making it difficult to compare the findings and develop a consensus.

Muscle strength, imbalance, and reaction time

It is clear that the forces developed by contraction of musculature are important for ambulation; however, it is unclear whether muscle contraction, evaluated in terms of strength, imbalance of extensors relative to flexors, or reaction time, is a risk factor for injury.

Several studies have shown muscle strength or imbalance to be risk factors for ankle injury,[52] knee injury,[67] and overuse leg injury.[11] In a prospective study of risk factors for ankle sprain in collegiate athletes, Baumhauer *et al*[52] found ankle strength imbalances in athletes who sustained injury compared with those who did not. Lower ratios of dorsi- to plantar flexion (0.373 in the injured group versus 0.348 in the uninjured group), and higher ratios of eversion to inversion (1.0 in the injured group versus 0.8 in the uninjured group) were found in athletes who sustained ankle injury. No differences in peak torque about the ankle were found between uninjured and injured subjects; however, within subjects, increased plantar flexion strength was found in the injured ankle (mean (SD) 72.20 (23.33) ft lbs of torque) compared with the uninjured ankle (mean (SD) 68.33 (19.26) ft lbs). Soderman *et al*[11] found a decreased ratio of hamstring to quadriceps strength to be a risk factor for traumatic leg injury (OR = 0.95) and increased hamstring to quadriceps ratio to be a risk factor for overuse leg injury (OR = 1.13) in female soccer athletes. Ekstrand and Gillquist[67] studied injuries in male soccer players and found those who suffered non-contact knee injuries had significantly reduced quadriceps strength at 30°/s and 180°/s on the injured leg compared with the uninjured leg. There was, however, no difference in ratios of hamstring to quadriceps strength in injured versus uninjured players.

Conversely, Ostenberg and Roos[35] did not find quadriceps and hamstring strength to be risk factors for all injuries considered as a group among female soccer players. Furthermore, Beynnon *et al*[53] found that ankle strength was not a risk factor for ankle injury in collegiate athletes. Milgrom *et al*[20] did not find an association between quadriceps strength and lateral ankle sprain in male infantry recruits.

With regard to muscle strength, two studies[11 52] found an association between muscular imbalance and injury, and one[67] reported an association between decreased muscle strength and injury. Three studies[20 35 53] showed no association between muscle strength and injury. It is difficult to compare the findings of these investigations because different planes of motion, testing speeds, sports with different inherent risks, and various male to female ratios were studied. Isokinetic dynamometers used to measure strength in terms of torque generated about a specific joint provide important information; however, these tests are performed with the subject non-weight bearing, and cannot duplicate the speeds of physical activity and injury mechanism.

Muscle reaction time—that is, the time lag between joint perturbation and muscle activation—considers the temporal response of musculature.[53] To date, only one study has prospectively investigated the association between muscle reaction time and injury. Beynnon *et al*[53] found that the time lag between dorsiflexion perturbation and activation of the tibialis anterior muscles and gastrocnemius muscles, and between inversion perturbation and activation of the peroneal brevis, longus, and tibialis anterior muscles were not ankle injury risk factors in collegiate athletes. There was, however, a trend in women who sustained ankle injury toward faster gastrocnemius reaction time and a delayed tibialis anterior reaction time in response to dorsiflexion perturbation. As the most common orientation of the ankle during a sprain is plantar flexion (created by contraction of the gastrocnemius) and inversion, the trend toward faster reaction time of the gastrocnemius in females may contribute to the incidence of ankle sprain. Additional research is needed to determine the relation between muscle reaction time and lower extremity injury.

Limb girth

The physiological cross sectional area of muscle is proportional to the maximum magnitude of force that it can develop. Therefore, limb girth has received interest as a potential risk factor for lower extremity injury with regard to the muscles' ability to stabilise and control the joint. Several studies have reported a relation between limb girth and lower extremity injury.

In a prospective study of risk factors for lower extremity stress fractures in male and female track athletes, Bennell *et al*[40] calculated corrected limb girth by subtracting the appropriate skinfold measurement from the limb circumference in order to more accurately estimate lean mass. Thigh girth was not shown to be a predictor of injury in men or women. There was an association between smaller gastrocnemius girth and injury in women; however, there was no association in men. Milgrom *et al*[20] found a significant relation between increased gastrocnemius circumference and incidence of lateral ankle sprain in male military recruits; however, no association was found between thigh circumference and injury. In a study of risk factors for lower extremity injury in 45 recreational basketball players, Shambaugh *et al*[75] found that injured athletes had a greater side to side discrepancy in quadriceps girth (mean (SD) 0.93 (0.73) cm) than uninjured athletes (mean (SD) 0.26 (0.57) cm). An injury was defined as an incident that caused the player to miss one or more games, and the ankle was the most commonly injured site. Limitations of this study include the fact that sex was not specified, and the sample size was relatively small.

The aforementioned studies found an association between limb girth and injury; however, the location at which limb circumference was measured, and the sex distribution and the sports investigated differed. Furthermore, differences in limb girth could result from lean muscle mass, body fat content, or bone geometry. It is therefore difficult to interpret the findings of studies in which limb girth is implicated as an injury risk factor. Bennell *et al*[40] attempted to address this issue by subtracting skinfold measurements from the limb girth values to provide a corrected limb girth for estimating lean mass. The measurement of limb girth, however, requires that the circumference of both limbs be taken at exactly the same distance from an anatomical landmark, and this is difficult to perform accurately. For this reason, Shambaugh *et al*[75] omitted gastrocnemius measurements from the findings of their study as they did not believe the measurement was reliable. Only radiographic techniques such as computed tomography scans can accurately measure limb girth, which were not used in any of the aforementioned studies because of the cost and increased risk associated with these techniques.

Postural stability

The ability of athletes to control the position of their centre of gravity has received attention as a potential risk factor for lower extremity injury because increased variation in postural stability is associated with an altered neuromuscular control strategy, increased intersegmental joint forces, and corresponding increased forces developed about the articular, ligamentous, and musculature structures. The relation between diminished postural stability and injury is unclear.

McGuine *et al*[76] used the NeuroCom Balance Master (NeuroCam International, Clackamas, Oregon, USA) in a prospective study of the relation between balance and ankle injury in 210 high school basketball athletes. Those with increased postural sway (diminished balance) showed a sevenfold increase in ankle sprains compared with those with normal balance. Similarly, Tropp *et al*[77] examined postural stability, using a force plate to measure postural sway, in male soccer players and found those with increased sway to be at an increased risk of ankle injury. Twelve of 29 subjects (42%) with increased postural sway incurred ankle sprains whereas 11 of 98 (11%) with normal values suffered ankle sprains. Only one study was found that investigated the association between postural stability and all lower extremity injuries. Soderman *et al*[11] used the Kinesthetic Ability Trainer 2000 (Breg Inc, Vista, California, USA) to measure postural sway of female soccer athletes and found those with diminished balance to be at increased risk of sustaining a leg injury (OR = 0.31).

Two studies reported no association between postural stability and injury. Hopper *et al*[18] assessed static balance by measuring the time in seconds that female netball athletes could maintain unilateral balance, both with eyes open and eyes closed. There was no association between the amount of time an athlete could maintain unilateral balance and injury. Beynnon *et al*[53] evaluated postural stability in collegiate athletes participating in soccer, field hockey, and lacrosse using the NeuroCom Balance Master, and found no difference in balance between those who sustained ankle injury and those who did not.

In summary, three studies[11 76 77] have reported an association between diminished balance and injury, and two[18 53] have found no association. The ability to maintain balance is dependent on visual cues, vestibular function, and somatosensory feedback from structures in the lower limb.[78] Additional research is needed into muscle reaction time in conjunction with postural sway to conclusively determine whether subjects with diminished balance possess central or peripheral alterations of the neuromuscular system. To date, only one study[53] has used this approach in a prospective research design.

Anatomical alignment

The intersegmental joint forces and the structures that must resist them—for example, articular surfaces, ligaments, and musculature—are related through anatomical alignment of the joints and skeletal system. Therefore, alignment of the hip, knee, and ankle has received substantial interest as a potential risk factor for lower extremity injury.

Two studies have reported an increased incidence of ACL rupture in athletes with a narrower femoral intercondylar notch. Souryal and Freeman[79] investigated the association between notch width and ACL injury in 902 high school athletes involved in all sports. A notch width index (NWI) was calculated by dividing the width of the intercondylar notch by the width of the distal femur at the level of the popliteal groove, based on radiographic measures. Twenty ACL injuries were incurred, 14 of which resulted from non-contact mechanisms and six from contact. Girls who suffered non-contact

Table 2 Intrinsic risk factors for injury

Risk factor	Sport	Sex	Injuries studied	Study type	Effect of risk factor	Ref.
Age	Soccer	f	All	PRF	Increased incidence in athletes older than 25 (age range studied 14–39)	35
	Soccer	m,f	All	PRF	Increased incidence in athletes older than 14 (age range studied 6–17)	34
	Indoor soccer	m,f	All	EPI	Increased risk in men older than 25, and in girls between 12 and 15 (age range studied 7 to early 50s)	36
	Military training	m,f	All	PRF	Increased risk in men aged 25–35 (age range studied 17–35)	38
	Australian football	n/a	Lower extremity muscle	PRF	Increased incidence of hamstring and calf strain among athletes older than 23; but no difference for quadriceps strains	37
	Australian football, field hockey, basketball, netball	m,f	Lower extremity, back	EPI	Increased incidence 26–30 years (age range studied 9–56)	15
	Soccer	m	All	PRF	Increased incidence in athletes 14–16 years of age *v* 16–18 years	16
	Basketball	m,f	Ankle	PRF	Increased incidence among younger athletes	22
	Soccer	m	All severe	PRF	No difference in incidence of injury, but injury type differed by age	17
	Soccer	f	Lower extremity	PRF	No association between age and injury	11
	Dancers	m,f	Lower extremity	PRF	No association between age and injury	39
	Netball	f	Lower extremity, back	PRF	No association between age and injury	18
	Track	m,f	Lower extremity, back, stress fractures	PRF	No association between age and injury	40
Gender	Basketball	f	All	PRF	Increased risk of all injuries as a group in females	50
	Soccer	m,f	All	PRF	Increased risk of all injuries as a group in females	34
	Military training	m,f	All	PRF	Increased risk of all injuries as a group in females	38, 51
	Military training	m,f	ACL	EPI	Increased risk of ACL tears in females	42
	European team handball	m,f	ACL	EPI	Increased risk of ACL tears in females	14
	Basketball	m,f	Ankle	PRF	Increased risk of grade I sprain in females; but no difference for grade II, III sprain	19
	Basketball	m,f	All	PRF	Increased risk of all injuries as a group in males and increased risk of knee injury in females	8
	Australian football, field hockey, basketball, netball	m,f	Lower extremity, back	EPI	Males at increased risk of injury compared with females	15
	Indoor soccer	m,f	All	EPI	No difference in incidence of all injuries, but females had an increased risk of knee injury and males had an increased risk of ankle injury	36
	Track	m,f	Lower extremity, back stress fractures	PRF	No difference in relative risk ;but risk factors were different between males and females	40
	Soccer, field hockey, lacrosse	m,f	Ankle	PRF	No difference in relative risk; risk factors differed between males and females	53
	32 high school sports	m,f	All	PRF	No association between gender and injury	54
	Dancers	m,f	Lower extremity	PRF	No association between gender and injury	39
	Soccer, field hockey, lacrosse	m,f	Ankle	PRF	No association between gender and injury	52
Phase of menstrual cycle	European team handball	f	ACL	PNRCS	Increased risk during week before and after start of menstrual period	14
	n/a	f	ACL	EPI	Increased risk on days 1 and 2 of menstrual period	55
	n/a	f	ACL	EPI	Increased risk during ovulatory phase	56
Previous injury	Soccer	m	All severe	PRF	Increased risk with previous injury	17
	Australian football	n/a	Lower extremity muscle	PRF	Increased risk with previous injury	37
	Dancers	m,f	Lower extremity	PRF	Increased risk with previous injury	39
	Basketball	m,f	Knee	PRF	Increased risk with previous injury	8
	Soccer	m	Ankle and knee	RCT	Increased risk with previous injury	26
	Military training	m	Ankle	PRF	Increased risk with previous injury	20

Table 2 Continued Intrinsic risk factors for injury

Risk factor	Sport	Sex	Injuries studied	Study type	Effect of risk factor	Ref.
	Basketball	m,f	Ankle	PRF	Increased risk with previous injury	22
	Volleyball	m,f	Ankle	PCS	Increased risk with previous injury	60
	Basketball	m,f	Ankle	RCT	No association	21
	Soccer	m	Ankle	PRF	No association	61
	Soccer, field hockey, lacrosse	m,f	Ankle	PRF	No association	52
Inadequate rehabilitation	Soccer	m	All	PRF	Increased risk with inadequate rehabilitation of injury	62
	Soccer	m	All severe	PRF	Increased risk with inadequate rehabilitation of injury	17
	Australian football	n/a	Knee - ACL	PRF	Increased risk with inadequate rehabilitation of injury	63
Aerobic fitness	Military training	m,f	All	PRF	Increased risk in recruits with fewer push ups, slower run times, lower VO_2MAX and smoking cigarettes	38
	Military training	m,f	All	PRF	Increased risk with slower run times	51
	Soccer	m	All severe	PRF	Increased risk with slower reaction time in response to an optical stimulus	17
	Military training	m,f	Lower extremity	PRF	Increased risk in females with slower run times and increased risk in males with fewer push ups	65
	Netball	f	Lower extremity, back	PRF	Increased risk with greater jump height, cycle work and power	18
	Soccer	f	All	PRF	No association between fitness measures and injury	35
	Military training	m	Ankle	PRF	No association between fitness measures and injury	20
Body size	Soccer	m,f	All	PRF	Increased risk in males of greater height; but no association in females	34
	Australian football	n/a	Lower extremity muscle	PRF	Increased risk with increased height for quadriceps strain; but no association for hamstring and calf strain	37
	Military training	m,f	Lower extremity	PRF	Increased risk with low and high BMI for males and increased risk with shorter height for females	65
	Military training	m	Ankle	PRF	Increased risk with greater ($wt \times ht^2$)	20
	Military training	m,f	All	PRF	No association between height, weight, or BMI and injury	38
	American football	n/a	All	PRF	No association between ((wt/ht) × 100) and injury	7
	Soccer	f	All	PRF	No association between BMI and injury	35
	Physical education students	m,f	All	PRF	No association between height, weight, or BMI and injury	66
	Dancers	m,f	Lower extremity	PRF	No association between BMI and injury	39
	Track	m,f	Lower extremity, back stress fractures	PRF	No association between height, weight, lean mass, fat content and injury	40
	Soccer, field hockey, lacrosse	m,f	Ankle	PRF	No association between height or weight and injury	52,53
	Basketball	m,f	Ankle	PRF	No association between height or weight and injury	22
Limb dominance	Soccer	m	All severe	PRF	No association of ankle or non-contact knee injury; but increased incidence of contact knee injuries in dominant leg	17
	Soccer	m	All	PRF	Increased risk of ankle injury in dominant leg; but no association of muscle strain	67
	Australian football	n/a	Lower extremity muscle	PRF	Increased quadriceps strain in dominant leg; but no association with hamstring or calf strain	37
	Soccer, field hockey, lacrosse	m,f	Ankle	PRF	Increased incidence in left leg dominant	52
	European team handball	m	All	PRF	No association between limb dominance and injury	6
	Soccer, field hockey, lacrosse	m,f	Ankle	PRF	No association between limb dominance and injury	53
	Soccer	m	Ankle	RCT	No association between limb dominance and injury	26
Generalized joint laxity	Soccer	f	All	PRF	Increased risk with increased laxity	35
	Soccer	f	Lower extremity	PRF	Increased risk of trauma with increased laxity; but no association between overuse injury and generalized laxity	11
	All collegiate sports	m,f	Lower extremity	PRF	No association in females; but increased risk with decreased laxity in males	68

Table 2 Continued Intrinsic risk factors for injury

Risk factor	Sport	Sex	Injuries studied	Study type	Effect of risk factor	Ref.
	American football	m	All	PRF	No association between generalized laxity and injury	70
	Netball	f	Lower extremity, back	PRF	No association between generalized laxity and injury	18
	Soccer, field hockey, lacrosse	m,f	Ankle	PRF	No association between generalized laxity and injury	52,53
Joint specific laxity	Soccer	m	All	PRF	Increased risk of knee injury with increased medial knee laxity; but no association between ankle laxity and ankle injury	30
	Soccer	m	All	PRF	Increased risk of all injuries as a group with increased knee laxity	67
	Soccer	m	All severe	PRF	Increased risk of ankle and knee injury with increased joint laxity	17
	Soccer, field hockey, lacrosse	m,f	Ankle	PRF	Increased risk with greater talar tilt exam in males; but no association in females	53
	American football	m	Ankle	PRF	Increased risk with greater talar tilt exam	71
	Basketball	m,f	Ankle	RCT	No association between ankle laxity and injury	21
	Soccer, field hockey, lacrosse	m,f	Ankle	PRF	No association between ankle laxity and injury	52
Muscle tightness	Military training	m	All	PRF	Increased risk with high and low levels of hamstring tightness	38
	Military training	m	Lower extremity	PRF	Increased risk of Achilles tendinitis with increased gastrocnemius tightness	73
	All collegiate sports	m,f	Lower extremity	PRF	No association between muscle tightness in females and increased risk of injury with greater tightness in males	68
	Basketball	m,f	Ankle	PRF	Increased risk with improper stretch, warm up	22
	Soccer	m	All	PRF	No association between muscle tightness and injury	30
Range of motion	Soccer	f	Lower extremity	PRF	Increased risk with increased knee hyperextension and increased risk of overuse injury with right/left differences in ankle ROM and hamstring flexibility	11
	Military training	m	Lower extremity	PRF	Increased risk of Achilles tendinitis with greater inversion, but no association with eversion/inversion and stress fractures	73
	Soccer, field hockey, lacrosse	m,f	Ankle	PRF	Increased risk with increased eversion in females, but no association between ROM and injury in males	53
	Physical education students	m,f	All intramural	PRF	No association between ROM and injury	66
	Dancers	m,f	Lower extremity	PRF	No association between ROM and injury	39
	Basketball	m,f	Ankle	RCT	No association between ROM and injury	21
	Military training	m	Ankle	PRF	No association between ROM and injury	20
Muscle strength, imbalance	Soccer, field hockey, lacrosse	m,f	Ankle	PRF	Increased risk with ankle strength imbalances	52
	Soccer	f	Lower extremity	PRF	Increased risk of trauma with low hamstring to quadriceps ratio and increased risk of overuse with high hamstring to quadriceps ratio	11
	Soccer	m	All	PRF	Decreased quadriceps strength on injured side compared with uninjured	67
	Soccer	f	All	PRF	No association between quadriceps and hamstring strength and injury	35
	Military training	m	Ankle	PRF	No association between quadriceps strength and injury	20
	Soccer, field hockey, lacrosse	m,f	Ankle	PRF	No association between ankle strength and injury	53
Muscle reaction time	Soccer, field hockey, lacrosse	m,f	Ankle	PRF	No association between reaction time and injury; trend for injury in females with slower tibialis anterior and faster gastroc reaction time to dorsi flexion perturbation	53
Limb girth	Track	m,f	Lower extremity, back stress fractures	PRF	Increased risk with smaller calf girth in females; but no association in males, and no association of thigh girth in males or females	40
	Basketball	n/a	Lower extremity	PRF	Increased risk of injury with greater right/left difference in thigh girth	75

Table 2 Continued Intrinsic risk factors for injury

Risk factor	Sport	Sex	Injuries studied	Study type	Effect of risk factor	Ref.
	Military training	m	Ankle	PRF	Increased risk of ankle injury with increased calf girth and no association between thigh girth and injury	20
Postural stability	Basketball	m,f	Ankle	PRF	Increased risk with increased sway (e.g. diminished balance)	76
	Soccer	m	Ankle	PRF	Increased risk with increased sway (e.g. diminished balance)	77
	Soccer	f	Lower extremity	PRF	Increased risk with increased sway (e.g. diminished balance)	11
	Netball	f	Lower extremity, back	PRF	No association between postural sway and injury	18
	Soccer, field hockey, lacrosse	m,f	Ankle	PRF	No association between postural sway and injury	53
Anatomical alignment	All high school	m.f	ACL	PRF	Increased risk with narrower femoral intercondylar notch width	79
	Football, ice hockey, basketball soccer, gymnastics, volleyball	m,f	ACL	PRF	Increased risk with narrower femoral intercondylar notch width	80
	Military training	m	Lower extremity	PRF	Increased risk with tibial valgum, increased Q angle	81
	Basketball	n/a	Lower extremity	PRF	Increased risk with greater side to side differences in Q angle, rearfoot valgus and leg length discrepancy	75
	Runners	m,f	Lower extremity overuse	PRF	Increased risk of shin injuries with greater tubercle-sulcus angle and knee varus and increased risk of all overuse with decreased leg length difference	82
	Military training	m	Ankle	PRF	Increased risk with increased leg length, foot length, foot width; and no association between tibial varum/valgum, hip external/internal rotation or tibia length and injury	20
	Soccer, field hockey, lacrosse	m,f	Ankle	PRF	Increased risk in females with increased tibial varum; but no association in males	53
	Physical education students	m,f	All	PRF	No association of hip, knee, rearfoot alignment or leg length and injury	66
	Soccer	f	Lower extremity	PRF	No association of Q angle and injury	11
Foot Morphology	Military training	m	Lower extremity	PRF	Increased risk of stress fractures with high arches	84
	Military training	m	Lower extremity	PRF	Foot and knee overuse injury associated with increased arch height	86
	Military training	m	Lower extremity	PRF	Increased risk of stress fractures with pes planus or cavus foot types; but no association between incidence of ITB syndrome or PFPS and foot type	73
	Football, cross country	m,f	Knee, ankle	PRF	Knee pain associated with pronated or supinated foot types; but no association with ankle sprain	85
	Runners	m,f	Lower extremity, back	PNRCS	Lateral, bony, foot/ankle injury associated with high arches and medial, soft tissue, knee injury associated with low arches	87
	Physical education students	m,f	All	PRF	No association between arch index and injury	66
	Runners	m,f	Lower extremity overuse	PRF	No association between arch index, heel valgus and injury	82
	Soccer, field hockey, lacrosse	m,f	Ankle	PRF	No association between foot type and injury	53
	Basketball	m,f	Ankle	RCT	No association between foot type and injury	21

ACL, Anterior cruciate ligament; EPI, epidemiological; PRF, prospective study of potential risk factors; RCT, randomised clinical trials; PNRCS, prospective non-randomised comparative study; n/a, not presented; BMI, body mass index; ROM, range of motion; ITB, iliotibial band; PFPS, patellofemoral pain syndrome.

ACL injuries had significantly decreased intercondylar width ratios (NWI = 0.165) compared with all girls as a group (NWI = 0.217 (0.041)). Likewise, boys who suffered non-contact ACL injuries had significantly decreased intercondylar width ratios (NWI = 0.214) compared with all boys as a group (NWI = 0.239 (0.040)). There was no significant difference in NWI between athletes who suffered contact ACL injuries and uninjured athletes.

LaPrade and Burnett[80] investigated the relation between femoral intercondylar notch width and ACL tears in 213 collegiate athletes participating in football, ice hockey, basketball, soccer, gymnastics, and volleyball. A femoral NWI was calculated as described above, although the radiographs were taken with the subject positioned differently. Seven ACL injuries were incurred, six of which resulted from non-contact mechanisms and one from contact. As in the aforementioned study, the average NWI for injured knees was significantly decreased (female, 0.200 (0.010); male, 0.188 (0.013)) compared with uninjured knees (female, 0.238 (0.037); male, 0.244 (0.036)). These two studies show that a decreased femoral intercondylar notch width is a risk factor for ACL injury; however, it remains unclear whether this is due to a smaller ACL and corresponding decreased material properties of the ligament or mechanical impingement as a result of reduced notch width.

The investigation of other anatomical alignment measures has yielded conflicting results. Milgrom *et al*[20] found a significant relation between increased leg length, increased foot length, increased foot width, and the risk of lateral ankle sprain in male military recruits. There was, however, no effect between knee alignment (distance between the knees during stance used as an indirect measure of tibial varum/valgum), internal and external hip rotation, or tibial length, and injury. Shambaugh *et al*[75] reported that recreational basketball players who sustained lower extremity injury had a greater side to side difference in quadriceps (Q) angle (2.71 (1.4)° *v* 1.26 (1.1)° in the injured and uninjured group respectively) and increased side to side differences in weight bearing rearfoot valgus (11.7 (3.4)° *v* 7.0 (3.5)°). Greater leg length discrepancy was also reported in the injured group; however, the units of measurement were not presented. Cowan *et al*[81] measured coronal and sagittal knee alignment, Q angle, and leg length discrepancy in 246 male military recruits and found those with severe knee valgus alignment (RR = 1.9, 95% CI = 1.1 to 3.3) and Q angle greater than 15° (RR = 1.5, 95% CI = 1.0 to 2.3) to be at increased risk for overuse lower extremity injuries. Beynnon *et al*[53] found that, in women, increased tibial varum was a risk factor for ankle sprain; however, in men, it was not a risk factor. Furthermore, Wen *et al*[82] investigated the association between anatomical alignment and overuse lower extremity injury in 255 runners participating in a marathon training programme. An injury was defined as an event with a gradual onset that resulted in a modification or reduction in training. The following anatomical measurements were collected: tubercle-sulcus angle (the angle between a vertical line through the centre of the patella to the centre of the tibial tubercle taken with the subject seated and knee flexed to 90°); standing knee varus; and leg length difference. Ninety overuse injuries were sustained. An increased tubercle-sulcus angle and increased knee varus were associated with shin injury. More lower extremity injuries occurred in athletes with decreased leg length discrepancy.

Several studies reported no association between anatomical alignment and subsequent injury. Twellaar *et al*[66] found no differences in leg length inequality, pelvic obliquity, knee alignment (distance between the knees during stance) or rearfoot position between uninjured and injured physical education students in a prospective study of intrinsic risk factors for lower extremity injury. Likewise, Soderman *et al*[11] did not find Q angle to be a leg injury risk factor in a prospective study of female soccer athletes.

With regard to anatomical alignment, five studies[20 53 75 81 82] reported an association between abnormal anatomical alignment and injury, whereas two[11 66] found no association. In addition, two studies have shown that reduced femoral intercondylar notch width is a risk factor for ACL injury.[79 80] Abnormal alignment may lead to decreased function and increased discomfort.[83] However, there is no agreement in the literature about the characterisation of abnormal alignment or the methods of measuring it. The studies reviewed here are difficult to compare as they differ in anatomical structures measured, statistical analyses used, and sports investigated.

Foot morphology

Like anatomical alignment of a joint, foot morphology has an important effect on the relation between the ground reaction force and the axes of rotation of the ankle, knee, and lower extremity as well as the corresponding forces developed on these structures. This has served as the rationale for studying the relation between the biomechanical behaviour of the medial longitudinal arch and the incidence of lower extremity injury. The methods of quantifying an abnormally high or low arch differ greatly and, consequently, disparate results exist.

Several studies have reported a relation between foot morphology and injury. In a prospective study of 295 male military recruits, Giladi *et al*[84] measured the arch non-weight bearing and classified it as low, average, or high; however, the criteria for the assessment were not presented. Those with high arches were found to have a greater incidence of stress fractures of the tibia, femur, and foot compared with those with low arches. Dahle *et al*[85] investigated the relation between foot type and occurrence of knee and ankle injury in 55 athletes participating in American football and cross country running. Foot type was assessed during stance and classified as pronated, supinated, or neutral using three criteria: calcaneal inversion/eversion; presence or absence of medial bulge at the talonavicular joint; and visual assessment of a line joining the medial malleolus, navicular, and first metatarsal-phalangeal joint. A significant relation was found between athletes who suffered knee pain and those who were classified with pronated or supinated foot types; however, no relation was found between foot type and incidence of ankle sprain. In a prospective study of military trainees, Cowan *et al*[86] photographed the right foot during weight bearing, digitised the photographs and made the following measurements: arch width, soft tissue arch height, navicular height, a ratio of navicular height to foot length, and a ratio of navicular height to dorsum height. Those with increased arch height were found to be at a significantly increased risk of overuse foot and knee injuries (OR = 6.1, 95% CI = 2.17 to 17.30).

Williams *et al*[87] investigated the association between arch structure and lower extremity and back injury in 40 recreational and team runners. An arch ratio was calculated by dividing arch height, from the floor to the dorsum at 50% of the foot length, by foot length, from the posterior aspect of the calcaneus to the first metatarsal-phalangeal joint. Subjects were separated into high arch (ratios of at least 0.356) and low arch (ratios less than 0.275) groups. Subjects possessing an arch ratio of between 0.275 and 0.356 were excluded from participation. Injuries were different between the two groups. Those with high arches had more lateral structure, bony, and foot/ankle injuries whereas those with low arches had more medial structure, soft tissue, and knee injuries. The most common injuries in the high arch group were plantar fasciitis, lateral ankle sprains, and iliotibial band syndrome, and only the fifth metatarsal sustained stress fractures. The most common injuries in the low arch group were general knee pain, patellar tendinitis, and plantar fasciitis, whereas metatarsal stress fractures were sustained on the second and third metatarsals.

Only one study has examined feet shod as well as barefoot. Kaufman *et al*[73] investigated 423 military recruits and calculated a static arch index by dividing the height of the navicular by foot length. A dynamic contact area ratio was calculated by dividing contact area collected beneath the midfoot region (from a point between the calcaneus and the cuboid to the metatarsal heads) by contact area collected beneath the entire foot (excluding the toes) using the Tekscan (Boston, Massachusetts, USA) foot pressure measurement system. An association between pes planus (contact area ratio greater than 8.10) and pes cavus (contact area ratio less than 4.14) foot types and increased incidence of stress fractures was found, but there was no relation between iliotibial band syndrome or patella femoral pain and foot structure.

Several studies found no association between foot morphology and injury. Wen *et al*[82] measured arch index, a ratio of height of the navicular to foot length, and weight bearing heel valgus in a study of overuse lower extremity injuries in distance runners and found that minor variations in lower extremity alignment were not risk factors for injury. Twellaar *et al*[66] measured the medial longitudinal arch using a footprint. An arch index was created by dividing the width of the weight bearing area of the midfoot by the width of the weight bearing area of the forefoot. No relation between arch index and injury was found in male and female physical education students. Beynnon *et al*[53] used the same methodology as Dahle *et al*[85] to assess the foot type of division I collegiate athletes and found no relation between anatomical foot type and ankle injury. Barrett *et al*[21] separated basketball players into three anatomical foot type categories: neutral, cavus, or hyperpronator. The criteria for classification of foot type were not presented, and no significant relation between foot type and ankle injury was found.

In summary, five studies[73 84–87] have reported an association between foot morphology and injury, whereas four[21 53 66 82] have shown no association. This discrepancy may be due in part to a lack of consistency in quantifying foot morphology. To conclusively establish the relation between foot structure and lower extremity injury, an objective, quantifiable method must be developed and used. In addition, it is important to study contact biomechanics of the foot inside the footwear in which the athlete is likely to incur injury.

Table 2 presents a synthesis of intrinsic risk factors for injury.

CONCLUSIONS

Prevention of injury remains an important goal for clinicians and researchers. However, to prevent lower extremity injury, the risk factors must be established. Many intrinsic and extrinsic risk factors have been implicated for lower extremity injury; however, at present there is little agreement. There is general consensus that the incidence of injury is greater in competition than training sessions, that injury risk is greater on artificial turf than grass or gravel, that previous injury, when coupled with inadequate rehabilitation, is a risk factor for subsequent injury, and that a reduced femoral intercondylar notch width is a risk factor for ACL injury. In addition, there is strong evidence that the use of ankle tape or brace reduces the risk of ankle injury.

With regard to ACL injuries in particular, it is clear that the risks include being female, incurring a previous ACL injury followed by inadequate rehabilitation, having a narrower femoral intercondylar notch width, competing in games compared with practice sessions, and wearing edge-style cleats compared with other cleat designs.

For ankle injury, the risk is higher in collegiate basketball than high school basketball, suggesting that higher skill levels may increase injury incidence. There is some indication that bracing or taping may reduce the risk of ankle injury, especially in athletes with a previous ankle injury. Furthermore, generalised joint laxity does not appear to be a risk factor for ankle injury.

The risks for lower extremity stress fractures include having high arches or a supinated foot type, increased age at the onset of menarche, and a decreased bone mineral content.

Findings on other risk factors are less clear. The lack of consensus may stem from dissimilar baseline risks associated with different sports, differences in the techniques used to measure the same potential risk factors, disparities in statistical analysis, varying injury definitions and methods used to classify injury severity, and the timing and frequency of data collection.

This review illustrates the importance of well controlled prospective investigations. Future studies should also be prospective in design, use a sufficient sample size to ensure adequate statistical power, include adequate numbers of males and females when studying the effect of sex on injury risk, involve the collection of exposure data accounting for both competitions and training sessions, and use established methods for identifying and classifying injury severity. Once risk factors for lower extremity injury are identified, intervention studies may be used to reduce the incidence and severity of injury along with the associated medical costs.

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