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Prevention of knee injuries in sports

A systematic review of the literature

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Aim. **We reviewed evidence regarding risk factors associated with incidence of knee injuries both to assess the effectiveness of prevention strategies, and to offer evidence-based recommendations to physicians, coaches, trainers, athletes, and researchers.**

Methods. **We searched electronic data bases without language restriction for the years 1966 - September 1, 2001, identified citations from reference sections of research papers retrieved, contacted experts in the field, and searched the Cochrane Collaboration. Of the 328 citations identified, we emphasized the results from the 13 reports that compared alternative methods to prevent knee injury and assessed the methodologic quality of these reports using a standardized instrument.**

Results. **Five studies addressed the effectiveness of bracing in football players; these studies showed no consistent evidence of benefit. Two studies comparing alternative cleat designs and a controlled study testing the effects of adjustments in the ski boot/binding system were difficult to interpret because of inadequate reporting of methodology. Six prospective studies that addressed the impact of conditioning and training showed promise of proprioception and neuromuscular training for protection against knee injury. We identified serious flaws in study design, control of bias, and statistical methods; the median quality scores ranged from 11 to 56 (out of 100).**

Conclusion. **Structured training programs that emphasize neuromuscular and proprioceptive training offer encouraging evidence for the prevention of knee injuries. However, flaws in study design and implementation have limited the effectiveness of work in this field. A rigorously implemented research program is needed to address this critically important sports medicine problem.**

KEY WORDS: Knee injuries, prevention and control - Knee injuries, epidemiology - Anterior cruciate ligament - Meta-analysis.

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Injuries to the lower extremity, especially the ankle and knee, are the most common cause of loss of practice and game time among athletes in many sports. Knee injuries, most notably tears of the anterior cruciate ligament (ACL) and the medial collateral ligament (MCL), are particularly severe and may result in long-term sequelae.[1] These injuries account in various sports for 15-50% of all injuries.[2-4] In the general population of the United States, an estimated annual incidence of 1 in 3,000 ACL injuries accounts for about 100,000 injuries annually.[5] ACL injuries alone result in 50,000 surgeries each year in the United States.[6] Studies in Sweden and the United States indicate that knee ligament tears, especially ACL injuries, are cost-

TABLE I.—*Results of field studies comparing alternative methods to prevent knee injuries.*

	Author (country)	Year	Study design	Population	Study groups (# athletes)	Outcomes (knee injuries)	Median quality score †
Equipment							
Bracing	Hewson (US)[33]	1986	Cross-sectional series*	450 College football players over 8 football seasons	1) Unbraced (226) 1977-1981 2) AKS (224) 1981-1985	1) 6 ACL, 40 MCL, 4 MCL/ACL, 3 others 2) 5 ACL, 33 MCL, 4 MCL/ACL, 6 others	18
	Quillian (US)[34]	1987	Cohort	244 High school football players over 2 seasons	1) Unbraced (194) 2) AKS (50)	1) 6 MCL/ACL, 6 others 2) 2 others	20
	Rovere (US)[35]	1987	Cross-sectional series*	Varsity football players at 1 University over 4 seasons	1) Unbraced 1981-1982 2) AKS (50) 1983	1) 17 MCL, 2 ACL, 4 others 2) 19 MCL, 4 ACL, 6 others	28
	Grace (US)[36]	1988	Cohort	694 High school football players (114 dropped out)	1) Unbraced (250) 2) Single-hinged brace (247) 3) Double-hinged brace (83)	1) 6 MCL, 1 ACL, 4 others 2) 15 MCL, 2 ACL, 2 MCL/ACL, 18 others 3) 2 MCL, 3 others	35
	Sitler (US)[37]	1990	RCT	1,396 Cadets in intramural football over 2 seasons	1) Unbraced (705) 2) Donjoy Brace (691)	1) 25 MCL, 12 ACL 2) 12 MCL, 4 ACL	53
Footwear							
	Cameron (US)[38]	1973	Prospective cohort	2,839 High school football players over 2 seasons	1) Cleats (2,055) 2) Heelplate (52) 3) Soccer shoes (266) 4) Swivel shoes (466)	189 Knee Injuries 1) 162 (7.9%) 2) 3 (5.8%) 3) 14 (5.3%) Total = 179 (8.1%) 4) 10 (2.1%)	11
	Hauser (Germany)[39]	1989	RCT	1,150 Skiers from area around Munich	1) Group with ski bindings tested and set properly (460) 2) Group with no specific change in ski equipment (690)	1) 81 (17.6%) Skiers reported one or more events of an injury; 0.7 LEER injuries/ 1,000 falls; 89.5 inadvertent releases/ 1,000 skiers' days 2) 169 (24.5%) Skiers events of injury; 24 LEER injuries/1,000 falls; 75.4 inadvertent releases/1000 skier's days	15
	Lambson (US)[40]	1996	Cohort	3,119 High school football players on 9 teams	1) Flat (812) 2) Screw-in (66) 3) Pivot disk (10) Total (888) 4) Edge cleats (2,231)	1) 3 ACL Tears 2) 1 ACL Tear 3) No ACL Tears Total 4 ACL Tears 4) 38 ACL Tears	27
Conditioning/ training							
	Cahill (US)[41]	1978	Cross-sectional series*	2,481 athletes on 8 high school football teams over 8 seasons	1) No conditioning (1,254) 1969 - 1972	1) 85 knee injuries, 19 knee surgeries	23

(Con't)

TABLE I.—*Continued.*

Author (country)	Year	Study design	Population	Study groups (# athletes)	Outcomes (knee injuries)	Median quality score †
				2) Conditioning (1,227) 1973 - 1976	2) 50 knee injuries 7 knee surgeries	
Ettlinger (US)[9]	1995	Cohort	Expert skiers over 3 years 1991-1994	1) No training (25 ski areas; 4,700 staff) 2) ACL awareness training (20 ski areas; 4,000 staff)	1) Increased umber of ACL injuries from 23/year to 29/year 2) Decreased number of ACL injuries from 31/year to 16/year after training	20
Caraffa (Italy)[42]	1996	Cohort	20 adult soccer teams over 3 seasons	1) Untrained 2) Proprioception training	1) 70 ACL tears 2) 10 ACL tears	30
Wedderkopp (Denmark)[43]	1999	RCT	22 High school team handball players over 1 season	1) Untrained (126) 2) Proprioception and targeted conditioning (111)	1) 8 knee injuries 2) 2 knee injuries	56
Hewett (US)[44]	1999	Cohort	1,263 High school athletes on 43 teams over 1 season (basketball, soccer, volleyball)	1) Untrained girls (463) 2) Neuromuscular training in girls (366) 3) Untrained boys (434)	1) 5 MCL, 5 ACL 2) 1 ACL, 1 MCL/ACL 3) 1 ACL, 1 MCL	37
Heidt (US)[45]	2000	RCT	300 High school girl soccer players over 1 year (2 seasons)	1) No training (258) 2) Accelerated training (42)	1) 8 ACL, 6 MCL, 77 others 2) 1 ACL, 1 MCL, 5 others	29

AKS = Anderson knee stabler; ACL = anterior cruciate ligament; MCL = medial collateral ligament; LEER = lower extremity, equipment related. * Also called before-and-after study; † 100 possible points.

ly,[2, 7] and cause the longest duration of absenteeism and the most permanent disability of any sports injuries.[8, 9] Although many sports involve risk for knee injury, risk is particularly high for basketball and volleyball from landing and cutting.[10-16] For soccer,[8, 10, 17] football,[18-22] and rugby,[23] risk is increased from both cutting and direct contact. In addition, the incidence of ACL injuries increased dramatically among downhill skiers following the introduction of modern ski boots designed both to prevent ankle fractures and to protect the tibia.[24-30]

In this paper, we focused on the evidence for effective measures that clinicians can recommend to coaches and athletes to prevent knee injuries. After systematically reviewing and summarizing the literature concerning the science base for prevention, we assessed the data from randomized controlled trials (RCTs) and cohort studies that evaluated intervention strategies. RCTs and cohort studies provide the best available scientific evidence in the study of human health.[31]

Materials and methods

We identified citations from the reference sections of more than 30 textbooks of sports medicine, family practice and other primary-care specialties, orthopedics, and general surgery. We searched electronic databases* (*i.e.*, Medline from 1996-2001, Current Contents 1996-2001, Biomedical Collection 1993-2001, and Dissertation Abstracts) in all languages using the following subject terms: knee injury and sports injury. We then limited the search using the terms prevention and control, etiology, and epidemiology. We identified further citations from the reference sections of the research papers retrieved, contacted experts in the field (including the first authors of RCT's or cohort studies addressing prevention of knee injuries), and searched the database of the Cochrane Collaboration (an international network of experts who conduct systematic searches for relevant citations).[32] We excluded papers

*The search included entries through August 2001.

TABLE II.—*Standardized scoring instrument for manuscript abstraction.*

Study name	Points
Experimental design	
Statement of research question (prior hypothesis)	4
Source of sample	5
Inclusion/exclusion criteria	6
Randomization	10
Examiner/analyst blinding	4
Selection bias addressed	2
Information bias addressed	2
Description of intervention	7
Comparison of participants to eligible decliners	3
Comparison of participants to dropouts	3
Independent validation of data	1
Power calculations (sample size requirements)	3
Clear method to evaluate outcome variable defined	3
Appropriateness of method	3
Addressed possible confounders	
Age	1
Gender	1
Skill level	1
Conditioning	1
Prior lower extremity injury	1
Sport	1
Competition *vs* practice	1
Playing surface	1
Medical supervision	1
Shoes	1
Taping or bracing	1
Education	1
Appropriateness of method of adjustment	4
Data presentation and statistical analysis	
Description of tests	6
Use of relative risk or odds ratio	2
Use of confidence intervals or p values	3
Multivariate techniques	4
Regression coefficients (if multivariate tech. used)	3
Addressed issues of multiple testing	2
Presentation of data	
Demographic data	2
Confounders	2
Comparability groups	2
Colinearity	2
Total (Possible 100)	

that did not provide primary research data, that addressed treatment or rehabilitation rather than prevention, or that provided previously published data. All articles were screened by the same reviewer. From 328 citations identified in our search, we found 182 articles that reported: a) the risk for knee injury in various sports, b) the identification of risk factors for knee injury, c) alternative methods to provide external support to the knees, d) the effect of bracing on performance, or e) comparisons of alternative methods to prevent knee injury. Of these, 13 reports compared alternative methods to prevent knee injury (Table I).[9, 33-45]

We modified a scoring instrument used previously to evaluate the methodologic quality of cohort studies and RCTs in sports medicine (Table II).[46-51] Reviewers were blinded to the primary authors' names and affiliations, but not to study results (since blinding of reviews to results has been shown to have little effect in practice).[52] Each citation was then evaluated independently by 3 reviewers. Following independent evaluation, the reviewers met to compare scores and to review and reconcile differences in interpretation.

To calculate the statistical significance of data presented in the papers that did not provide significance levels or confidence intervals, we assumed that injuries occurred independently for any one participant and that the average number of playing hours was approximately equal for all participants playing the same sport. Based on these assumptions, the number of injuries follows a binomial distribution, and the significance of observed results can be calculated as an exact test.[53]

Two reviewers independently extracted data from the analytic studies and RCTs to determine when pooling was appropriate. Because of the heterogeneity of the populations examined, the interventions, study methodology, and statistical results, we were able to pool only published results from studies with similar study designs (*e.g.*, RCTs) that examined the effect of knee bracing in football. We calculated odds ratios and relative risks using Epi Info [54] and report Fisher's exact p values.[53]

Background

Risk factors for knee injury

Factors contributing to injury can be classified as either extrinsic or intrinsic.[10] Extrinsic factors thought to be related to knee injury include factors related to specific sports,[10, 55-57] equipment,[56, 58-61] playing surface,[56, 62-69] shoes,[20, 22, 70] supervision of activities including games and practices,[58, 71] and weather conditions [59-61] (Table III). The interaction of shoe, cleat, and playing surface with each other [72-79] and with environmental factors (*e.g.*, temperature [80] and surface wetness [81]) all contribute to risk for knee injury.

Limited data exist on other extrinsic factors, although the occurrence of injury late in a game and early in a

TABLE III.—*Intrinsic (personal) and extrinsic (environmental) risk/preventive factors which may play a part in knee injuries.*

Intrinsic factors
Demographics
— extremes of age
— sex
Physical build
— height
— weight
— body fat
Physical defects/anatomic variations
— femoral neck anteversion
— increased Q angle in women
— static posture limb alignment
— hyperpronation
— narrow intracondylar notch
— small ligament size
— poor proprioception
— joint instability
— varying estrogen levels/ovulation
Physical fitness
— low aerobic endurance/conditioning
— fatigue
— strength and balance between flexors and extension
— increased flexibility of muscles/joints
— poor sporting skill/coordination
Extrinsic factors
Psychological factors
— risk acceptance
Previous injury
Sports-related factors
— type of sport
— exposure (contact, planting, cutting, landing, stopping)
— nature of event
— role of opponents and teammates
Equipment
— protective equipment (*e.g.*, braces)
— shoe/surface interface
Venue/supervision
— state of floor or ground
— safety measures
— conduct of match
— rules
— referee's application of rules
Weather conditions
— temperature
— relative humidity

season is consistent with fatigue or poor conditioning. In addition, several factors serve to protect athletes from knee injury: rules to control and minimize unnecessary or hazardous contact among players, appropriate officiating to ensure compliance with event rules, responsible and experienced coaches and trainers to prepare athletes for competitive activities, and safe and well-kept fields and floors that are free of hazards. Although few of these activities have been subject to rigorous scientific review (and will not be addressed here), they could warrant implementation based on their positive impact on the quality of play. Similarly, debate exists over the role in injury occurrence of natural and artificial playing surfaces. However, no evidence from controlled studies is available to resolve this controversy.

Intrinsic factors that could be associated with knee-injury risk include age,[59, 82] inexperience,[61] body size,[83, 84] static posture,[85] joint laxity,[55, 86-90] limb alignment (including hyperpronation),[85, 88-91] muscle fatigue,[58, 92, 93] poor proprioception,[86] female gender,[83, 84, 94-103] increased Q angle in female athletes,[55, 104] intracondylar notch dimensions,[55, 84, 105, 106] estrogen levels,[14, 87, 88, 107-110] ovulation,[97, 111, 112] the ratio of the hamstring to quadricep muscle strength [113, 114] (as well as absolute strength of these muscles [83, 87, 89, 114-116]), ligament size,[10] arch structure,[117] genetic predisposition,[118] and psychological factors.[56] In addition, previous knee injury clearly increases risk for injury.[113, 119, 120] Narrowing of the intercondylar notch has been associated with ACL injury,[84, 105, 121-128] especially noncontact injuries,[125, 126] although not all studies confirm this finding.[129, 130] The postulated mechanism of injury involves the movement of the ACL over the lateral femoral condyle or external rotation and abduction leading to excess anterior tibial translation or rotation of the femur on the tibia.[124, 125, 131] However, with the exception of one early study of high school football players,[132] no evidence exists to support ligament or joint laxity,[10, 133-137] increased Q angles,[14] or muscle imbalance [138] as predisposing factors to knee-ligament injury.

In recent years, reports of ACL injuries have been more frequent among female athletes relative to male athletes in comparable sports at the high school, college, and professional levels.[2, 10, 11, 14, 89, 96, 139-144] The tendency of women to perform activities more erect, with knees and hips closer to extension when cutting or landing, leads to increased quadriceps activity relative to hamstrings and may be the cause of increased risk of ACL injury.[87, 131, 145] The hamstring muscle clearly has a role in stabilizing the knee joint, but whether this stabilizing effect can protect the knees of competitive athletes is unknown.[3, 116, 146-153] The apparent increase in flexibility/joint laxity in females has not been associated directly with increased rates of knee injury in young women,[10, 154] although there is evidence that genu recurvatum may diminish proprioceptive sense.[155]

Except in circumstances where the external mechanical torques are created (*e.g.*, by skis or by direct contact during blocking or tackling in football), the 3 main injury-producing movements are planting and cutting, straight knee landings, and rapid, 1-step stops.[156-159] During these movements, the ACL tightens with the extremes of extension and contraction associated with internal or external rotation of the knee.[160] In a study of ACL ruptures in 24 female basketball players, investigators found that 14 were injured while landing from a jump, 9 while pivoting, and 1 after being knocked down.[14] All had been in training; 13 reported moderate intensity and 11 reported heavy training. Another study of 53 ACL injuries found that 33 were affected by a valgus force, 6 by a varus force, and 14 were unable to describe the circumstances of injury.[120] Although the MCL acts as the primary stabilizer for the knee during both valgus and external axial movements, the ACL becomes primary when the MCL ruptures.[161]

Results

Methods to prevent knee injuries

Bracing is the most extensively investigated intervention developed to prevent knee injury.[162] Laboratory studies of cadavers, mechanical surrogates, or volunteers indicate that braces can lessen impact momentum, increase impact duration, and decrease the peak load on the ACL.[163, 164] Braces are most effective for large-mass, low-velocity impacts,[165] but any effect is modest.[166] Prophylactic knee braces are least effective for small-mass, high-velocity activities with free hip/ankle motion and flexed knee.[165]

Descriptive studies of prophylatic knee braces focus entirely on football players, with particular emphasis on protection of the MCL from contact injury. In these studies, some investigators report protective effects [167-169] whereas others find no effect or even increased risk.[170] Analytic studies that include comparison groups show a similar inconsistency in results.[34, 37, 39, 162]

Some evidence supports adverse effects from knee brace usage, including muscle fatigue,[171-173] decreased quadricep and hamstring activity,[174] and no proprioceptive benefit.[165, 174] Because the body adapts, these effects might not persist for all athletes [175] and might not affect athletes uniformly.[176] During tests of speed and agility, investigators report slowing in straight forward running [177-179] and figure 8 tests,[178] but no effect on backward sprints and agility, except among inexperienced users.[177, 179] Different brands of knee braces had variable affects on speed and agility in young athletes.[178-180] Functional knee braces (designed to support injured knees) tend to compromise performance more than prophylatic braces (designed to support uninjured knees), especially during dynamic activities.[178, 180, 181]

Analytic research also has been used to assess the effectiveness of specific training and/or physical conditioning in preventing knee injury.[41-45] Preseason conditioning is advocated not only to minimize fatigue and enhance athletic performance, but also to prevent injury.[182] Programs have been developed to emphasize the prevention of knee injuries [183, 184] based in part on the demonstrated benefits of training on ligaments among experimental animals.[185] Descriptive studies of U.S. Army cadets also suggest benefit of such programs.[183, 186] A study of 11 female high school volleyball athletes found that an intensive 6-week jump-training program not only improved vertical leap, but also decreased landing forces and improved muscle balance and control, which could protect the knee from injury.[184]

Prospective studies of alternative methods to prevent knee injury

Study quality.—Individual scores for the papers examined ranged from 7 to 58 (out of a possible 100). Papers in the upper tertile had median scores (*i.e.*, combining the scores of the 3 reviewers) of 30 to 55. Those in the middle tertile scored from 21-29.5 and those in the lowest tertile scored 11-20. Studies with randomized designs scored consistently higher than cohort studies (median: 43 *versus* 24). This relationship remained even when points assigned for randomization were excluded from the computation.

None of the 4 RCTs reviewed reported whether allocation of subjects was blinded. In addition, details of randomization were not reported adequately in any of these RCTs. (The design of cohort studies does not allow either blinding or randomization.) The lack of attention to possible confounding effects and to both information and selection biases hampered interpretation of results. Lack of attention to complete specification of statistical methods was evident. For example, power calculations were never reported; denominators for rates varied across studies (*e.g.*, knees, players, or player-hours) with no justification given; choices of controls were rarely random; and the potential effect of multiple interventions was not assessed.

Equipment.—Eight studies have been published on the use of equipment to prevent injuries to the knee (Table I). Five addressed the effectiveness of bracing in football players,[34-37] 2 compared alternative cleat designs of football shoes,[38, 40] and 1 tested the effects of adjustments in the ski boot/binding system.[39]

One RCT compared the experience of 1,396 U.S. Army cadets during 2 years of practice and games in 8-man intramural football (quality score = 53%).[37] Donjoy (double-hinged, single-upright) prophylactic braces were assigned randomly to 691 athletes, whereas 705 athletes served as unbraced controls. Injuries were confirmed independently by 3 orthopedists. During the 2-year period, 21,570 athlete exposures were monitored. Overall, 16 injuries occurred among the braced group (4 ACL, 12 MCL) and 37 occurred among the controls (12 ACL, 25 MCL). The overall injury rates were significantly elevated among controls (3.4/1,000 *versus* 1.5/1,000 athlete exposures, $p<0.05$). The patterns for ACL injury, both moderate and severe, were similar for both groups. Contact and noncontact injuries were not distinguished.

Two cohort studies addressed the effectiveness of bracing.[34, 36] In a study of 694 high school football players (quality score = 35%), athletes and their families were given the choice to use knee braces and selected 1 of 2 types.[36] During 2 13-week seasons, 114 athletes were dropped for reasons unrelated to knee injury, leaving 247 players using single-hinged braces, 83 using double-hinged braces, and 250 without braces. The players were matched for size (in pairs), position, and varsity/junior varsity status; 1 athlete in each pair was given a prophylactic brace, whereas the other was not braced. Athletes using single-hinged braces had a 3.7-fold increase in knee injury ($p<0.001$), whereas those using double-hinged braces reported a nonsignificant increase in knee injuries. Four ACL tears occurred among the athletes using single-hinged braces, none occurred among the double-hinged group, and 1 tear occurred among the unbraced controls. In another cohort study of high school football players, 50 athletes were assigned to wear a double-hinged prophylactic brace (Anderson Knee Stabler), and 194 players served as unbraced controls (quality score = 20%).[34] During 2 seasons, only 1 knee injury was diagnosed among braced players, while 13 injuries were reported among unbraced controls, including 1 ACL tear ($p<0.05$).

Two further studies designed to assess the effectiveness of prophylactic bracing used a cross-sectional series design (*i.e.*, before-and-after studies).[33, 35] Investigators reviewed medical records covering 8 collegiate football seasons at 1 university (quality score = 18%).[33] Braces were not used during the first 4 seasons, but linebackers and tight ends were required to wear a double-hinged brace (Anderson Knee Stabler) during the second 4 seasons. During the nonbracing period, 226 athletes competed in 515 practices and games, and players suffered 54 knee injuries (34 season-ending), including 10 ACL tears. During the bracing period, 224 athletes participated in 504 practices and games; braced players reported 48 knee injuries (29 season-ending) with 9 ACL tears. The authors of this study concluded that prophylactic bracing had no measurable effect on knee injury. A similar study reviewed the records of another college football program over 3 seasons without bracing followed by 3 seasons in which all players wore a double-hinged brace (Anderson Knee Stabler) (quality score = 28%). Investigators found similar injury rates among both groups (*i.e.*, 23 knee injuries during nonbracing seasons, 29 during bracing seasons).[35] ACL tears were reported among 2 players without braces and 4 with braces. Noncontact injuries were reported among 3 athletes without braces and 7 with braces. Because both these studies use a cross-sectional series design, interpretation of results is complicated by the inability to control for confounding by factors such as differences in the study populations, changes in playing surface, and changes in conditioning programs.

Results from the pooled analysis of these before-and-after studies [33, 35] showed no significant decrease in either total injuries ($p=0.64$), MCL injuries ($p=0.67$), or ACL injuries ($p=0.86$) with the use of knee bracing. When we pooled the data from cohort studies [34, 36] for total injuries, there was no significant difference for total injuries when interventions using double-hinged braces were used [odds ratio (OR)=0.83, $p=0.85$]. However, when interventions using single hinged braces were also included, bracing was associated with an increase in total injuries (OR=2.24; p=0.01). For the single RCT [148] examining bracing, it was associated with statistically significant decreases in both total injuries (OR=0.41; 95% confidence interval [CI] = 0.2, 0.85, p=0.01), but not in MCL or ACL injuries (p=0.52 and 0.08, respectively).

Two analytic studies of knee injury prevention have analyzed innovations in shoe design. A 3-year cohort study of 3,119 high school football players on 9 teams assessed the effect of cleat design on ACL injury (quality score = 27%).[40] In this study, the Edge cleat design was compared to 3 non-Edge-type cleats (*viz*, Flat, Screw-in, and Pivot disk designs). A total of 2,231 athletes using Edge cleats suffered 38 ACL tears (rate: 17/1000), while 888 players using non-Edge-type cleats reported 4 ACL tears (rate: 4.5/1000), a 3-fold difference (p=0.0066). Another cohort study comparing 466 football players using specially designed swivel shoes to players using standard cleats (2,055 players), heel plates (n=52), or soccer shoes (n=266) demonstrated a 3.5-fold decrease in knee injuries (quality score = 11%).[38] Information about study design, nature of injury, and method of allocation of athletes to different groups was not reported.

Another approach to the prevention of lower extremity injury involved correction of faults in the ski boot/binding system and proper setting (quality score = 15%).[39] When an experimental group (selected randomly from volunteers) was provided with proper testing and setting of bindings as well as ski poles with special grip design and was compared to a control group with no specific intervention, a statistically significant decrease in injuries was reported (17.6% *versus* 24.5%).

Conditioning/training.—Six published analytic studies address the impact of training on the prevention of knee injuries. The 1st, a cross-sectional series, focused on assessing the effectiveness of preseason conditioning on the incidence and severity of knee injuries among 8 high school football teams (quality score = 23%).[41] A conditioning program conducted for 5-6 weeks before the season began took place for 80 min during 3 days each week. Medical records for the 4 years before initiation of the training and the 4 subsequent years were reviewed. The number of reported knee injuries decreased from 85 to 50 after training (p<0.01). The authors did not report type of injury or coaching continuity, nor did they address the effect of the prohibition of below-the-waist blocking in 1973 (the 1st year of the conditioning program).

The 2nd, a prospective study, examined an ACL-awareness training program conducted for patrollers and instructors in 20 ski areas in Vermont and targeted at experienced Alpine professional skiers (quality score = 20%).[9] The investigators used video tape training to increase recognition and avoidance of injury risk, demonstrate proper fall technique, and enhance kinesthetic appreciation. The control population was selected from 22 ski areas not involved in the training. Injury data were collated from ski patrol reports, physician examinations, and workers compensation records. During the 2 years before training, an average of 31 ACL injuries occurred among patrollers and instructors. The number dropped to 16 in the year after training. During the same period, the 2-year average in the control areas increased from 23 to 29 ACL injuries. The authors concluded that this training program was cost-effective but their report did not provide data to support their contention.

The 3rd, a cohort study of proprioceptive training, was designed to prevent ACL injuries among male soccer players (quality score = 30%).[42] The members of 20 teams in amateur and semiprofessional leagues in Italy were given intensive, daily preseason proprioceptive training and 20 min of daily maintenance training during the season. Twenty teams with players of comparable age, training, and level of play who did not receive proprioceptive training served as controls. The 40 teams were served by a single hospital and were monitored and tested carefully over 3 seasons. The specially trained teams had 10 arthroscopically confirmed ACL injuries compared to 70 among the controls (p<0.001).

A 4th, an RCT conducted in Denmark, studied 237 female athletes aged 16-18 years on 22 team handball clubs ranging in skill from recreational to elite (quality score = 56%).[43] Eleven teams were assigned randomly to an intervention group that underwent specialized conditioning for a full season, including 10-15 min of ankle-disk training at each practice, as well as focused muscle-group training. Eleven control group teams, which received no special training, were matched according to age, practice time, playing level, floor composition (synthetic *versus* wood), and injury incidence in the previous season. The overall injury rate was significantly lower among the intervention group (0.34 *versus* 1.17 injuries/1,000 hours of practice, p<0.05; 4.68 *versus* 23.38/1,000 hours of games, p<0.01). Two knee injuries occurred among the intervention group, compared with 8 among the controls, but the difference was not statistically significant. Among the controls, risk for injury increased with more practice time; in the intervention group, risk for injury decreased with more practice time, findings that were consistent with a beneficial effect of the training program.

The 5th study was designed to evaluate the effectiveness of a neuromuscular training program on the incidence of knee injury in female athletes attending high schools in the Cincinnati, Ohio, area (quality score = 37%).[44] Fifteen girls' soccer, volleyball, and basketball teams implemented, a 6-week preseason neuromuscular development program that incorporated flexibility, plyometrics, and weight training to increase muscle strength and decrease landing forces. Fifteen girls' teams who elected not to use the program were used as a comparison group, and 13 untrained boys' teams were also monitored. A total of 1,263 athletes were followed closely during each playing season, including weekly injury reports from certified trainers. Serious injuries were evaluated by an experienced sports medicine physician. Fourteen serious knee injuries (defined as ruptures of the ACL or MCL) were diagnosed in the study; 9 were noncontact injuries. The rate of serious injury was decreased in the girls' teams receiving the preseason training compared to the untrained girls' teams (0.12/1000 athlete exposures *vs* 0.43/1000; p=0.06); the comparison of noncontact injuries was even more dramatic (0.35/1000 *vs* 0/1000; p=0.005). The rates in the intervention group were comparable to those seen the boys' comparison group (0.09/1000 overall, 0.05/1000 noncontact injuries).

In the 6th study of conditioning, 42 female high school soccer players were selected randomly from 300 athletes to participate in a 7-week acceleration training program that included sport-specific cardiovascular conditioning, plyometrics, coordination drills, as well as strength and flexibility training (quality score = 29%).[45] Injuries were diagnosed by a trainer blinded to the athlete's participation in the program and graded in severity by time lost to participation in games or practices. During 1 year of competitive soccer, 98 injuries were recorded, 7 in the training group (14.3%) and 91 (33.7%) in controls (p<0.05). One ACL tear (2.4%) and one MCL injury (2.4%) were diagnosed in the training group compared to 8 ACL tears (3.1%) and 6 MCL injuries (2.3%) in the controls (p>0.05). The authors concluded that this conditioning program lowered injury rates although there was no measureable affect on knee injuries.

Discussion

Our review of published evidence of interventions to prevent knee injuries supports the result that specialized training may decrease the injury rate, double-upright braces are preferable to single-upright braces, and single-upright braces may increase risk of injury. However, given the limitations of the reporting of study design and implementation, we cannot endorse widespread use of any of these interventions to prevent ACL tears and other knee injuries. Poorly designed and implemented studies also limit our ability to endorse the use of the only other preventive equipment interventions that have undergone prospective evaluation, alternative shoe design and correction of the ski boot/binding system. The most encouraging evidence for effective prevention of ACL injury comes from studies of neuromuscular and proprioceptive training. Two studies, a cohort study [42] and an RCT [43] support the use of proprioceptive training to prevent knee ligament injury. A 1999 cohort study of neuromuscular training [44] was encouraging, but exhibited methodologic problems such as lack of blinding of investigators and incomplete statistical methods. Particular attention has been drawn to the ratio of hamstring to quadriceps muscle development in neuromuscular training, especially in women whose hamstrings tend to less well developed than in men.[83, 114] Also an RCT reported in 2000 assessing the effectiveness of comprehensive, acceleration training did not demonstrate a protective effect on knee injury.[45]

The knee must provide stability to the athlete while allowing mobility during jumping and rapid changes in direction.[187] Two large bones held together by a complex of 4 major ligaments and various capsular structures support the body, allowing the knee to move through 3 rotational and 3 translational degrees of freedom. The ACL is placed at particular risk in extremes of flexion and extension as tension on the ligament peaks. Short of curtailing competition, the challenge is to protect the knee from external forces and to stabilize the joint against extremes of internal forces. In most instances, a critical stress can be removed if the foot can be freed rapidly from the playing surface. For example, the modification of football shoes in the

1970s used a larger number of shorter cleats. The principle behind the use of braces in football, on the other hand, is to cushion the joint from direct contact. Conditioning offers potential benefit in at least 4 ways — increased ligament strength, decreased muscle fatigue, enhanced proprioception, and muscle strength balance.

Knee injuries are a consequence of either direct contact or a noncontact movement involving deceleration, planting of the foot, and pivoting. Efforts to minimize contact injury (*e.g.*, rule changes in football) and equipment to protect players (*e.g.*, braces) are intended to reduce the risk for contact or minimize its effect on the joint. Presumably, any beneficial effect of conditioning or training results from increased knee strength and stability which reduces the harmful rotation that stretches ligaments to tearing.[188]

The most frequently studied intervention, braces for football players, has not been demonstrated consistently to prevent injury to the MCL or ACL.[162] The ideal brace should prevent knee injury, but not compromise performance or place the athlete (or other athletes) at risk for other injuries.[189] The ambiguity of past studies led the American Academy of Orthopaedic Surgeons to issue a position statement in 1987 concluding that prophylactic knee bracing had not been effective in reducing the number or severity of knee injuries, particularly, ACL injuries.[190] This statement, combined with cost and inconvenience, has contributed to the limited use of prophylactic knee braces in football. Because most prophylactic braces are designed to resist laterally applied impact loads near the joint,[47] as seen in blocking or tackling, we cannot assume any protection from injury due to other stresses like landing and cutting.

An ACL injury-prevention effort based on training to minimize risk in 3 major injury-producing activities (*i.e.*, planting and cutting, landing, and jumping) showed early promise but was not completed because of the death of the principal investigator.[191] A study of the contribution of lower extremity joints to energy dissipation during landings from different heights support the need to develop effective training in injury prevention techniques.[192] Several methodologic issues were identified in our review. For future studies in this field, well conducted RCTs are necessary. Whereas, a double-blind study is often not feasible for surveillance of athletic injuries (*e.g.*, braces are evident on wearers), both blinded allocation of subjects and blinded data analysis are essential to minimize bias. Although research on knee-injury prevention is fairly extensive, the most important data — those based on RCTs designed to address the effectiveness of an intervention to prevent knee sprains — are limited in both scope and implementation. In RCTs and cohort studies, subjects in both intervention and control groups should be subject to uniform, consistent, and ongoing monitoring (*i.e.*, surveillance and case ascertainment) of injuries. In calculating rates of injury, consideration must be given to the choice of denominators (*e.g.*, hours of participation *versus* numbers of games).[193] The denominator chosen should be appropriate for the intervention under the study and equivalent in the exposed and unexposed groups. More scrupulous attention to issues of bias and confounding are critical to understanding the effect of preventive interventions in this complex field. Rigorous statistical methods are essential. Finally, the data reporting should be improved so that the published data clearly support the conclusions. Review of the epidemiology of skiing injuries cited similar concerns.[58]

Based on this review, we recommend that the following research questions be addressed to advise coaches, trainers, and athletes on injury-prevention strategies: a) is a conditioning program that emphasizes both plyometrics and proprioception and is modeled on the ones developed for soccer players in Italy and high school athletes in the U. S. adaptable to other populations (*e.g.*, high school and college football or basketball players)? b) Will such programs effectively prevent knee injuries, especially among athletes with no previous history of injury? c) Are these interventions equally effective among female athletes (few analytic studies and only 3 RCTs have included women)? d) Are these interventions appropriate for all athletes, or do kinesiological and sport-specific considerations require different interventions? e) Which interventions are most effective among athletes with a history of previous knee injury? f) What clinical indicators can be used to help coaches and athletes determine when a player can return to competition without increased risk for further injury? g) What, if any, biological/anatomical/biomechanical measures can be ascertained easily before a season, warranting preventive actions (*e.g.*, special training) and h) what inherent behavioral aspects of sports injuries present particular challenges of access to data and compliance of study subjects (*e.g.*, will coaches give greater priority to injury intervention, or what will motivate athletes to maintain proper conditioning)?

Conclusions

Whereas this review identified many unanswered questions requiring further research, we can make only limited practical recommendations to coaches, trainers, and athletes. Coaches and trainers should emphasize injury prevention as much as skill development. Athletes who play for coaches with more experience and training are less likely to suffer injuries in competitive activities.[70] During games or practice, coaches should be sensitive to the effects of fatigue, and recognize that not only is performance compromised when players are tired, but the risk for injury is also greater.[194, 195] Preseason conditioning should be planned thoughtfully to optimize performance;[196] general as well as targeted conditioning might help prevent knee injury as fatigue has been shown to compromise proprioception.[197] Strength, agility, and flexibility must be emphasized during the season and the preseason. However, better research is needed to evaluate whether general and targeted training will reduce knee-injury rates.

Sports at all levels are popular and healthy activities practiced by millions of persons worldwide, but they are also a leading cause of preventable injury. Actions often endorsed for injury prevention could not be supported in this review of published evidence. Some actions (*e.g.*, adequate shoes and warming up) could have benefits beyond the prevention of knee injuries. Similarly, the assurance of safe fields and floors makes sense, but studies that examine whether they help prevent knee injuries are lacking. Research into the most effective means of preventing injury is crucial, as is effective interpretation of the science of sports injuries and its translation into practice.[198] This review of the existing literature on knee-injury prevention, one of the most common and serious injuries among athletes, suggests that much work remains to be done in this field.

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