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Prevention and Awareness for Knee and Hamstring Injuries

2018 International Olympic Committee consensus statement on prevention, diagnosis and management of paediatric anterior cruciate ligament (ACL) injuries

ABSTRACT

In October 2017, the International Olympic Committee hosted an international expert group of physiotherapists and orthopaedic surgeons who specialise in treating and researching paediatric ACL injuries. Representatives from the American Orthopaedic Society for Sports Medicine, European Paediatric Orthopaedic Society, European Society for Sports Traumatology, Knee Surgery & Arthroscopy, International Society of Arthroscopy Knee Surgery and Orthopaedic Sports Medicine, Pediatric Orthopaedic Society of North America and Sociedad Latinoamericana de Artroscopia, Rodilla y Deporte attended. Physiotherapists and orthopaedic surgeons with clinical and research experience in the field, and an ethics expert with substantial experience in the area of sports injuries also participated. Injury management is challenging in the current landscape of clinical uncertainty and limited scientific knowledge. Injury management decisions also occur against the backdrop of the complexity of shared decision-making with children and the potential long-term ramifications of the injury. This consensus statement addresses six fundamental clinical questions regarding the prevention, diagnosis and management of paediatric ACL injuries. The aim of this consensus statement is to provide a comprehensive, evidence-informed summary to support the clinician, and help children with ACL injury and their parents/guardians make the best possible decisions.

INTRODUCTION

The number of ACL injuries in children is rising.[1][2] ACL injuries in children create a level of concern that is more significant than in any other population with ACL injury. Do children who rupture their ACL mature similarly to their uninjured peers? Do they continue with sport? Do they prioritise their education and other interests over sport? Does an ACL injury and treatment change their lives? These young individuals have to live with their knee problem for the rest of their life, which may compromise their quality of life and increase the risk for further injury, meniscal tears and early onset osteoarthritis.[3] Compounding the problem is that there is very little high-quality evidence to guide decision-making in management of paediatric ACL injuries.[4]

Progress on these issues can only be made based on long-term follow-up in multicentre collaborations. Achieving progress requires a long-term commitment from those who have children's interests close at heart. Therefore, in October 2017, the IOC hosted an international expert group of physiotherapists and orthopaedic surgeons who specialise in treating and researching paediatric ACL injuries. Representatives from the following societies attended: American Orthopaedic Society for Sports Medicine (AOSSM), European Paediatric Orthopaedic Society, European Society for Sports Traumatology, Knee Surgery & Arthroscopy (ESSKA), International Society of Arthroscopy Knee Surgery and Orthopaedic Sports Medicine (ISAKOS), Pediatric Orthopaedic Society of North America and Sociedad Latinoamericana de Artroscopia, Rodilla y Deporte (SLARD).

Clinicians are charged with the responsibility of providing accurate information and effective treatment to this vulnerable population. Sharing information about the potential consequences of ACL injury and treatment in childhood to long-term knee health should be a central part of the shared decision-making process. Adult patients with ACL injury may develop symptoms and signs of osteoarthritis within 10 years of the index injury.[5] Therefore, the clinical concern is that a child who is injured at the age of 10 years could have symptomatic osteoarthritis by the age of 20. A quintessential question is what is the long-term prognosis after ACL injury in childhood? Having a definitive, evidence-based answer to this question would strengthen our confidence in clinical decision-making. Clearly, the answer to this question is not straightforward and depends on many factors, but one important point is that long-term outcomes

Box 1 Six fundamental clinical questions and relevant consensus statement topic(s)

Section 1: How can the clinician prevent ACL injuries in children?
Relevant consensus statement topic:
► Injury prevention

Section 2: How does the clinician diagnose ACL injuries in children?
Relevant consensus statement topic:
► Diagnostic tests and imaging

Section 3: What are the treatment options for the child with an ACL injury?
Relevant consensus statement topics:
► High-quality rehabilitation
► Surgical techniques
► The paediatric ACL graft

Section 4: What are the most important considerations when making treatment decisions?
Relevant consensus statement topics:
► Skeletal age assessment
► The decision for ACL reconstruction
► Risks associated with ACL reconstruction
► Management of associated injuries

Section 5: How does the clinician measure outcomes that are relevant to the child with an ACL injury?
Relevant consensus statement topic:
► Paediatric patient-reported outcome measures

Section 6: What are the clinician's role and responsibilities?
Relevant consensus statement topic:
► Ethical considerations

after ACL injury in childhood, including the development of osteoarthritis, have not been studied.

> *'Long-term outcomes after ACL injury in childhood, including the development of osteoarthritis, have not been studied.'*

Injury management is challenging in the current landscape of clinical uncertainty and limited scientific knowledge. Injury management decisions also occur against the backdrop of the complexity of shared decision-making with children and the potential long-term ramifications of the injury. This consensus statement addresses six fundamental clinical questions regarding the prevention, diagnosis and management of paediatric ACL injuries (box 1). By framing each topic around clinical questions, the aim of this consensus statement is to provide a comprehensive, evidence-informed summary to support the clinician, and help children with ACL injury and their parents/guardians make the best possible decisions.

CONSENSUS METHODS
A modified Delphi consensus process[6–8] was used to identify the topics to be addressed in this consensus statement. Experts were contacted by email in June 2016, and invited to respond to an electronic survey. A mix of open and closed questions were used to gather expert opinion regarding the key issues in the field. These responses were summarised and formed the basis of 18 statements regarding injury prevention, diagnosis, prognosis, surgical techniques, treatment decision-making, management and outcome measurement (see online supplementary file 1) .

A two-round consensus process was conducted, involving 19 content experts. Respondents rated the importance of the 18 predefined statements on an 11-point scale ranging from *not important at all* to *of utmost importance*. Consensus was defined as a mean ranking of at least eight points for each statement. After the first voting round, statements reaching consensus were removed, so that only statements that failed to reach consensus in the first voting round went through to the second voting round. The statements that finally reached consensus formed the topics that were discussed at the consensus meeting.

The IOC convened a consensus meeting of 21 experts in Lausanne, Switzerland in October 2017. The experts were identified by the IOC through the AOSSM, ESSKA, ISAKOS and SLARD member societies, and from physiotherapists and orthopaedic surgeons with clinical and research experience in the field. An ethics expert with substantial experience in the area of sports injuries also participated.

Section 1: injury prevention
This section addresses the fundamental clinical question: *how can the clinician prevent ACL injuries in children?* Prevention of ACL injury is important because of the potential for serious long-term consequences in those who sustain the injury, and because of the increased risk of reinjury to either knee.[9] Therefore, it is paramount that the principles of injury prevention are incorporated in the treatment of the child with ACL injury.

Substantial advances have been made in the development and application of ACL injury prevention programs across numerous pivoting sports. There is compelling evidence that ACL injury prevention programs work in skeletally mature patients—they reduce the number of athletes who sustain a primary ACL injury, and reduce the number of new ACL injuries among athletes who return to sport after primary ACL injury.[10–15]

The athlete's biomechanical movement patterns are a key modifiable risk factor for injury. Injury prevention programs target movement patterns by incorporating strength, plyometrics and sports-specific agility training.[16 17] Coach and athlete education on cutting/landing techniques (eg, wide foot position when cutting, flexed knee when landing) that avoid high-risk knee positions are also fundamental. Injury prevention programs are straightforward to implement because they require little to no equipment, and are performed as part of regular team training or physical education 2–3 times per week (figure 1).

'11+ For Kids' program

> *'Injury prevention programs should also be implemented early in the athlete's developmental process.'*

Injury prevention programs should also be implemented early in the athlete's developmental process. This will give the athlete the best opportunity to develop strong and favourable movement strategies. One well-established injury prevention program,[18] the 11+, has recently been modified (eg, adding falling techniques, making partner-based exercises more play-oriented) to suit the paediatric population (FIFA '11+ For Kids'). Completing

Figure 1 Injury prevention exercises incorporated into team training.

the program can reduce football-related lower extremity injuries by over half.[19] Children who complete the program also have improved motor control, balance tests and agility, compared with those who do not complete the program.[20]

Factors that might impact on injury prevention effectiveness

Well-designed injury prevention programs have the lowest injury rates and injury time loss.[18 21] But the effect of a well-designed injury prevention program is strongly influenced by how frequently athletes perform the training.[22–24] Therefore, consistent implementation and utilisation, and adherence across all levels of competitive play, is one of the biggest challenges facing the clinician. Those involved in youth sports, and clinicians who treat paediatric athletes with ACL injury have a responsibility to actively advocate for injury prevention in both a primary setting and for children who return to sport after an injury.

Section 2: diagnosis, clinical tests and imaging

This section addresses the fundamental clinical question: *how does the clinician diagnose ACL injury in children?* High-quality injury prevention programs are the first-line defence against the potential negative short-term and long-term consequences of ACL injury. However, if injury prevention efforts fail, timely and accurate diagnosis is important, since diagnosis is the starting point for effective management planning and shared decision-making. The clinician combines information from the patient's history, examination and clinical tests, and imaging to build the clinical picture that will inform diagnosis and treatment. Typically, a thorough history and clinical examination will enable the clinician to make an accurate diagnosis.

Clinical pearl 1

Haemarthrosis (acute swelling in the knee within 24 hours after a trauma due to intra-articular bleeding) following acute knee injury is an important clue suggesting structural knee injury.

Clinical pearl 2

Diagnosis can be more challenging than in adults because children may be poor historians, they may have greater physiological joint laxity (be sure to examine both knees) and MRI interpretation is more difficult given developmental variants in children.[25 26]

Clinical pearl 3

Due to the immature skeleton, children may sustain different knee injuries (eg, sleeve fracture of the patella, epiphysiolysis) than adults.

Consider starting the assessment by ordering plain knee radiographs for all paediatric patients with a haemarthrosis/suspected acute knee injury. This is because tibial eminence fractures and an ACL tear can present with a similar history and physical examination findings. It is also important to rule out other paediatric fractures (eg, epiphysial fracture, sleeve fracture of the patella). Perform an MRI to confirm the diagnosis of ACL injury and evaluate other soft tissue structures.[27] In children with an ACL injury, MRI may yield additional information to identify meniscal tears, other ligament injury or osteochondral injury. In children with a locked knee, an acute MRI is warranted to assess the presence of a displaced bucket handle meniscal tear or an osteochondral injury that may need prompt surgical treatment.

Measurement properties for clinical examination and MRI

> *'No isolated question, test or image can accurately identify an ACL injury, every time.'*

No isolated question, test or image can accurately identify an ACL injury, every time. The measurement tools available to the clinician are not perfect, but they do yield valuable information in the clinical context. Knowledge of the measurement properties of clinical tools helps the clinician balance the information gained from these tools. The negative predictive values of clinical examination and MRI for ACL tear and meniscal pathology are higher than the positive predictive values (table 1). This means that if the clinical examination and MRI are negative for injury, the chance of the patient having an injury is low. However, if the

Table 1 Diagnostic accuracy of clinical examination and MRI in intra-articular knee disorders (adapted from Kocher *et al*[27])

Diagnosis	Sensitivity (%)			Specificity (%)			Positive predictive value (%)		Negative predictive value (%)	
	Clinical examination	MRI	P value	Clinical examination	MRI	P value	Clinical examination	MRI	Clinical examination	MRI
ACL tear	81.3	75.0	0.55	90.6	94.1	0.39	49.0	58.6	97.8	97.1
Medial meniscus tear	62.1	79.3	0.15	80.7	92.0	0.03	14.5	34.3	97.6	98.8
Lateral meniscus tear	50.0	66.7	0.24	89.2	82.8	0.21	34.0	30.1	94.1	95.7

Clinical examination was patient history, physical examination and X-rays performed by a paediatric orthopaedic sports medicine specialist or a postresidency paediatric sports medicine fellow.

Figure 2 Child demonstrating how to hold terminal knee extension during single limb stance. This is an important marker of quadriceps control in ACL rehabilitation and prehabilitation.

tests are positive, it *does not* mean that the clinician can always reliably rule the diagnosis *in*.

Section 3: treatment of ACL injuries in children

This section addresses the fundamental clinical question: *what are the treatment options for the child with ACL injury?* Once the clinician is certain of the injury diagnosis, he or she first needs to know the available treatment options, and discuss these options with the child and the child's parents/guardian, so a shared decision can be made about how best to manage the knee injury.

The goals of treatment for the child with ACL injury are:

1. To restore a stable, well-functioning knee that enables a healthy, active lifestyle across the lifespan.
2. To reduce the impact of existing or the risk of further meniscal or chondral pathology, degenerative joint changes and the need for future surgical intervention.
3. To minimise the risk of growth arrest and femur and tibia deformity.

There are two treatment options that can help the child with ACL injury (with or without associated knee injuries) achieve these goals: high-quality rehabilitation alone (non-surgical treatment) and ACL reconstruction plus high-quality rehabilitation. In this section, the key components of high-quality rehabilitation for the child with ACL injury, and the options for ACL reconstruction surgical technique are described. Potential treatment decision modifiers are outlined in *Section 4*.

High-quality rehabilitation

High-quality rehabilitation is a critical component in the management of ACL injury, and the principles of rehabilitation are the same, irrespective of whether the child has had an ACL reconstruction or has elected for non-surgical treatment. Guidance for paediatric rehabilitation is extrapolated from clinical experience and research in adults, although it is uncertain whether adult principles apply to children.[28] Rehabilitation must be performed in close collaboration with the child's parents/guardians. Exercises and functional goals must be modified, not simply copied from the adult-oriented rehabilitation protocols that may be more familiar to many clinicians. This is because children are not small adults—they cannot be expected to perform unsupervised training independently with perfect technique. Qualified rehabilitation clinicians must supervise rehabilitation for the child with ACL injury.

> *'Rehabilitation must be performed in close collaboration with the child's parents/guardians.'*

> *'Children are not small adults.'*

Rehabilitation focus

Dynamic, multijoint neuromuscular control is the primary focus of ACL rehabilitation in children. For the youngest patients (with markedly open physes, aged <12 years), there is less emphasis on the development of muscular strength and hypertrophy. During maturation, and throughout the onset of puberty, rehabilitation strategies that more closely resemble those used with adult patients are appropriate, due to the increase in androgenic hormones.[29] These strategies must include heavier and externally loaded strength training.

> *'Rehabilitation must be thorough, and individualised to the child's physiological and psychological maturity to achieve successful outcomes.'*

Rehabilitation must be thorough, and individualised to the child's physiological and psychological maturity to achieve successful outcomes. Emphasise exercises that facilitate dynamic

Box 2   Recommended functional tests and return to sport criteria for the child and adolescent with ACL injury

For patients who choose ACL reconstruction
Prehabilitation
► Full active extension and at least 120 degrees active knee flexion
► Little to no effusion
► Ability to hold terminal knee extension during single leg standing (figure 2)
► **For adolescents**: 90% limb symmetry on muscle strength tests

For patients who choose ACL reconstruction OR non-surgical treatment
Phase I to phase II
► Full active knee extension and 120 degrees active knee flexion
► Little to no effusion
► Ability to hold terminal knee extension during single leg standing
Phase II to phase III
► Full knee range of motion
► 80% limb symmetry on single-leg hop tests, with adequate landing strategies
► Ability to jog for 10 min with good form and no subsequent effusion
► **For adolescents**: 80% limb symmetry on muscle strength tests

Phase III to phase IV: sport participation (return to sport criteria), and continued injury prevention
► Single-leg hop tests: >90% of the contralateral limb (with adequate strategy and movement quality)
► Performed gradual increase in sport-specific training without pain and effusion
► Confident in knee function
► Knowledge of high injury-risk knee positioning, and ability to maintain low-risk knee positioning in advanced sport-specific actions
► Mentally ready to return to sport
► **For adolescents**: 90% limb symmetry on muscle strength tests

Muscle strength testing should be performed using isokinetic dynamometry or handheld dynamometry/one repetition maximum. The type of test and experience of the tester are highly likely to influence the results. If using handheld dynamometry/one repetition maximum, consider increasing the limb symmetry criterion cut-off by 10% (ie, 90% limb symmetry becomes 100% limb symmetry). Clinicians who do not have access to appropriate strength assessment equipment should consider referring the patient elsewhere for strength evaluation.

important in the paediatric population, but currently are insufficiently studied.

Following surgical treatment, the graft type used for ACL reconstruction, and associated injury or surgery to other ligaments, menisci or articular cartilage, necessitate specific adjustments to the rehabilitation program. Rehabilitation programs should be designed to allow the child to participate in his or her team training sessions to maintain the social benefits of staying within the team. Parents or guardians should be active participants in the daily rehabilitation.[32] This may include assisting the child in technical and functional exercises during team training (eg, short passes in football).

Rehabilitation phases
Rehabilitation for the child with an ACL injury is organised into four phases (box 2; online supplementary file 2), with an additional prehabilitation phase for those who choose ACL reconstruction. Specific clinical and functional milestones should be met before progressing from one phase to the next.[33] Throughout the first two phases, the child should be guarded from cutting and pivoting activities during sport, free play and physical education classes in school.

Rehabilitation progression
The framework for progression through functional milestones is similar for ACL reconstruction and non-surgical treatment. However, there are different expectations for progression and time to return to full participation in sport. For all patients, rehabilitation progression must be guided by clinical and functional milestones (box 2), and return to full participation[34] is dependent on successfully achieving the return to sport criteria (box 2). Non-surgical treatment should last for at least 3–6 months.[35] Postoperative rehabilitation should last for a minimum of 9 months before return to full participation in preferred physical activities.[36]

Data from international registries suggest that young athletes are at high risk for a second ACL injury following an ACL reconstruction,[37] and the risk is highest in the first 12 postoperative months.[36 38] Therefore, consider advising the child athlete not to return to pivoting sport until at least 12 months following ACL reconstruction. Rehabilitation is also an excellent opportunity to train the uninjured leg, which might be important considering the risk of contralateral injury.[38] Once the child returns to sport, a comprehensive injury prevention program, emphasising biomechanical alignment and landing/cutting technique should be integrated with usual training.

'Consider advising the child athlete not to return to pivoting sport until at least 12 months following ACL reconstruction.'

Five considerations when designing rehabilitation programmes for the prepubescent child
Children who are close to skeletal maturity may follow rehabilitation[33] and return to sport guidelines[36 39] intended for adults. There are five important considerations for the prepubescent child:
1. Consider a home-based program, with emphasis on playful exercises and variation (figure 3) to discourage boredom.
2. Single-leg hop tests and isokinetic strength tests have larger measurement errors in the prepubescent population, so use these tests with caution.[40]

lower limb alignment and biomechanically sound movement patterns. Although this has been successfully implemented in rehabilitation programs for adolescents and adults, it has not yet been documented as extensively in children. The exercises are gradually progressed through phases II and III of the paediatric ACL rehabilitation protocol (box 2; online supplementary file 2) as part of sport-specific rehabilitation. See online supplementary file 2 for examples of exercises to consider in each rehabilitation phase. Reinjury anxiety and the patient's confidence in his or her injured knee impact on outcomes after ACL rehabilitation in adults.[30 31] These psychological factors are also likely to be

Figure 3 One example of an exercise that could be incorporated into a home-based ACL rehabilitation program.

3. Focus on evaluating the quality of movements during single-leg hop testing, instead of the leg symmetry index measures.
4. Tests and criteria to assess movement quality are yet to be validated, so the responsible clinician needs to have skills and experience in this area.
5. Return to sport criteria were designed and scientifically tested in the skeletally mature patient and are recommended for the child who is close to maturity.[36 41] The validity of these criteria in the prepubescent child is unknown.

Bracing

Many clinicians involved in non-surgical treatment of skeletally immature children recommend the child wear a protective brace during strenuous physical activities.[42] The child who has had surgical treatment typically wears a brace during the prehabilitation phase, until ACL reconstruction is performed. Following surgery, it is recommended that the child wears a protective knee brace through the successful completion of the functional milestones in rehabilitation phase I (usually 2–6 weeks postoperative, depending on concomitant surgical procedures). However, the effectiveness of bracing following ACL injuries or reconstruction in paediatric patients is unknown. Other considerations related to the use of a brace might be to prevent knee hyperextension or knee valgus/varus, to enhance the child's awareness of his or her injury and as a protective signal to others the child might encounter (eg, at school).
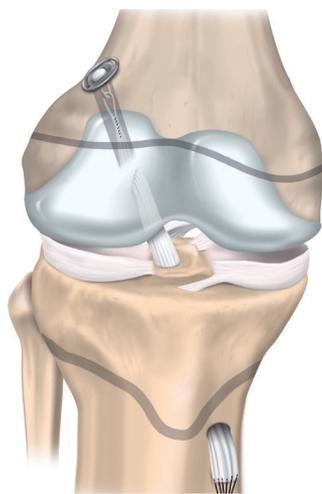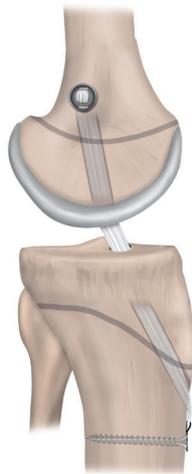

A. Anterior view   **B. Lateral view**

Figure 4 Transphyseal ACL reconstruction. (A) Anterior view and (B) lateral view.
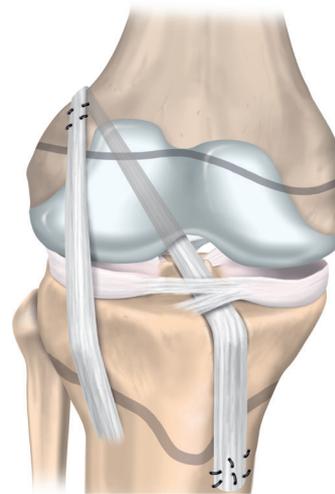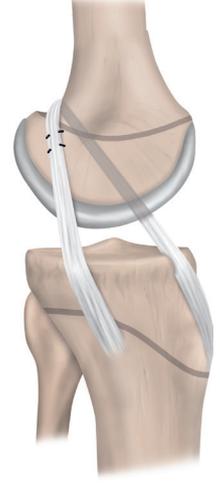
A. Anterior view   **B. Lateral view**

Figure 5 Physeal-sparing ACL reconstruction using an over-the-top technique with iliotibial band. (A) Anterior view and (B) lateral view.
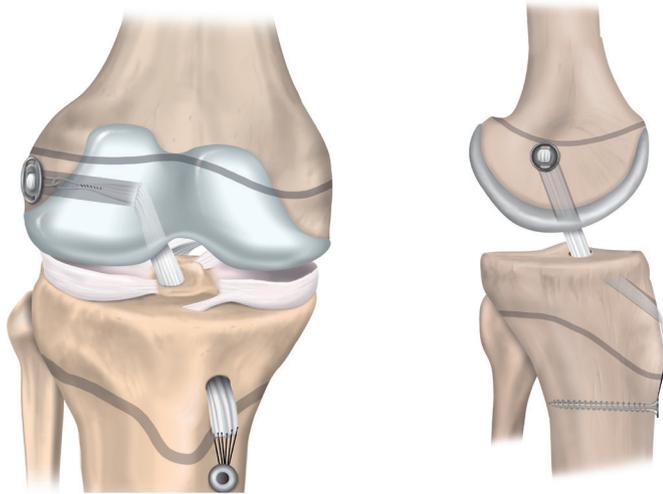
A. Anterior view   **B. Lateral view**

Figure 6 Physeal-sparing ACL reconstruction using an all-epiphyseal technique. (A) Anterior view and (B) lateral view.

Surgical techniques

The general principles of ACL reconstruction in adults also apply to the paediatric patient: use a well-positioned (soft tissue) autograft of adequate size, with adequate fixation to allow functional rehabilitation. Physeal damage should be minimised to avoid growth disturbance. Bone plugs and fixation devices should not cross the physis.[43–45]

Key indications for ACL reconstruction

There are three indications for paediatric ACL reconstruction:
1. The child has repairable associated injuries that require surgery (eg, bucket-handle meniscus tear, repairable meniscal lesion or osteochondral defect).
2. The child has recurrent, symptomatic knee giving way after completing high-quality rehabilitation.
3. The child experiences unacceptable participation restrictions (ie, an unacceptable modification of activity level to avoid knee giving way).

There are three possible techniques for paediatric ACL reconstruction.

Transphyseal ACL reconstruction

The transphyseal technique in the child is similar to the technique the surgeon would use for ACL reconstruction in adults. Single bundle transphyseal ACL reconstruction with a quadrupled hamstring graft is the most common (figure 4).[46–51] Therefore, because the surgeon is more likely to be familiar with the key elements of the procedure, it may reduce the risk of intraoperative complications. Ensure the diameter of the bone tunnels is as small as possible (<9 mm) to accommodate an appropriate size graft.[52] Similarly, to minimise physeal damage, orient the tibial tunnel as vertically and as centrally as possible while maintaining the anatomical position of the graft. On the femoral side, the surgeon should take care to avoid the perichondral ring. Drilling via the anteromedial portal can result in a tunnel that has an elliptical trajectory through the physis. Consider a slightly more vertical orientation than might be used for an ACL reconstruction in an adult patient, or choose a different drilling approach.
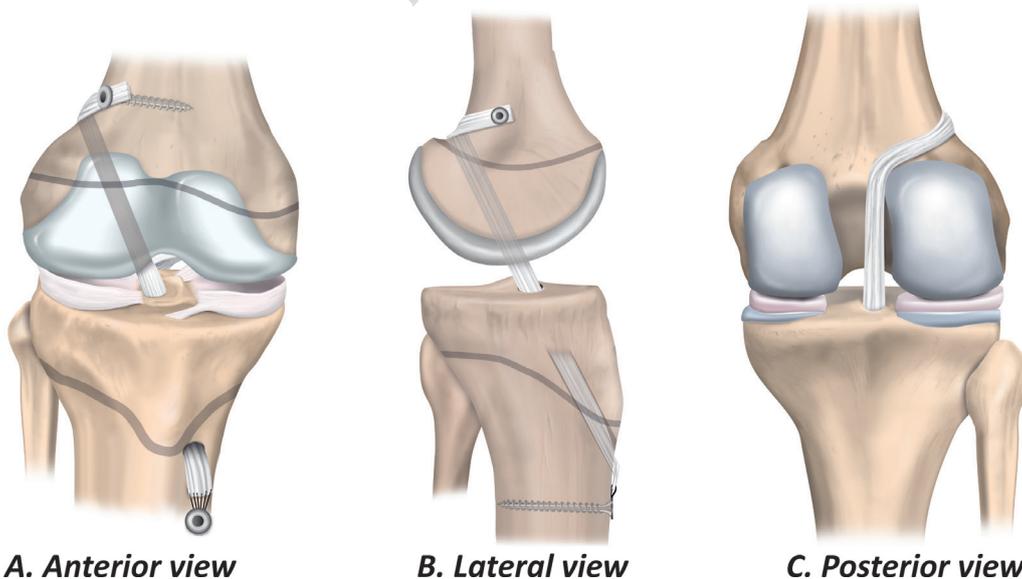
A. Anterior view   **B. Lateral view**   **C. Posterior view**

Figure 7 Partial transphyseal ACL reconstruction. (A) Anterior view, (B) lateral view and (C) posterior view.
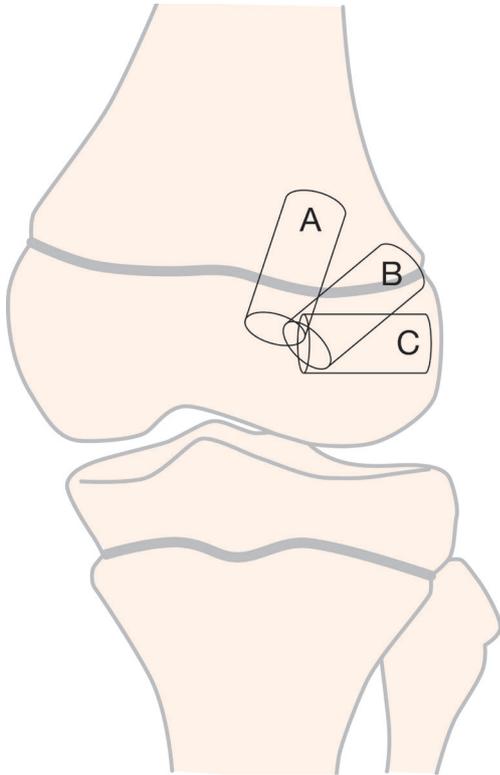
Figure 8 Three different options for femoral tunnel trajectories.

Physeal-sparing ACL reconstruction

Physeal-sparing techniques avoid physeal damage in patients with markedly open physes. The techniques include an over-the-top technique with a strip of the iliotibial band (figure 5),[53] and an all-epiphyseal procedure (figure 6).[54] In the all-epiphyseal procedures, use fluoroscopic visualisation to reduce the risk of physeal damage. When using the over-the-top technique, avoid femoral rasping to minimise the risk for damage to the perichondral ring.

Partial transphyseal ACL reconstruction

The partial transphyseal technique (figure 7) combines a *transphyseal tibial tunnel* with a *physeal-sparing technique on the femoral side*.[55–57]

Surgical principles and techniques for growth disturbance risk reduction

Drill hole trajectory and location influence the degree of risk to the physes (box 3 and figure 8). Knowledge of three key principles will help the surgeon minimise the risk to the physes during transphyseal ACL reconstruction:

1. Drilling at the periphery of the physis and the perichondral ring increases the risk of growth disturbance. Drill holes may be placed in an all-epiphyseal manner to allow for drilling at the native ACL footprint, while avoiding the physis. Precise tunnel placement is required when performing this technique to avoid damage to the undulating distal femoral physis.
2. Bone tunnel drill holes should be as vertical as possible (while still maintaining anatomic graft position) and as central as possible. This is especially important when drilling through the anteromedial portal. Drilling an oblique tunnel rather than a more vertical tunnel increases the amount of physis removed and increases the risk for growth disturbance.

3. Do not cross the epiphysis with hardware, implants or bone blocks. Fill bone tunnels with soft tissue, rather than leaving the tunnels open.

Graft choice and fixation

Only soft tissue grafts (not allografts) should be used for ACL reconstruction in paediatric patients with open physes. The quadrupled hamstring graft is most common.[47–51] A quadriceps tendon graft may be used.[56] The patella tendon *should not* be harvested in paediatric patients with open physes to avoid damage to the tibial tubercle apophysis. Allografts are not indicated in paediatric patients in most cases, since the use of allografts in paediatric ACL reconstruction has poor clinical outcomes.[58–60]

> *'The use of allografts in paediatric ACL reconstruction has poor clinical outcomes.'*

A novel technique involving the use of living-donor hamstring tendon allograft has been reported[49 61] to avoid the varied sterilisation techniques used in cadaveric soft-tissue allografts, and preserve of the neuromuscular unit of the growing patient.[62 63] However, long-term clinical outcomes are yet to be assessed.

Extracortical fixation of soft tissue grafts may be performed with a cortical button, suture, post or staple. Aperture fixation may be performed with interference screws, provided the screws do not cross the physis.

Graft incorporation

Data regarding ACL graft incorporation in children are scarce. Paediatric soft tissues have a greater biological growth potential compared with adults,[64 65] and cell migration and proliferation of ACL-fibroblasts slows as the person grows older.[66] The clinical relevance of the growth potential to paediatric ACL reconstruction is still unclear,[67] although there is a rationale from animal models that the paediatric ACL graft may remodel faster than the adult ACL graft.[68]

Adaptations and remodelling in the growing child

The ACL graft must adapt as the child grows. The graft may increase in length as the bone grows, and the bone tunnels may reduce in relative size.[69 70] It is uncertain whether the diameter of the intra-articular part of the graft becomes longer and thinner,[71] or not,[70] as the child grows. The graft does not *increase* diameter as the child grows, but may increase in length.[72]

With longitudinal bone growth after transphyseal ACL reconstruction, the graft may become more vertically oriented. This observation might be explained by the movement of the femoral fixation site with physeal growth or because the tibial tunnel aperture becomes relatively more posterior due to greater anterior growth of the proximal tibia. Other changes occurring as the child grows are secondary intercondylar notch narrowing, distal migration of the tibial and/or proximal migration of the femoral extracortical fixations and verticalisation of the Blumensaat line.[73] However, the long-term clinical significance of these growth-related changes is unclear.

Section 4: treatment decision modifiers

This section addresses the fundamental clinical question: *what are the most important considerations when making treatment decisions?* The key issues addressed relate to assessment of skeletal maturity, the decision for surgery or not, management of injuries to other knee structures and potential adverse events

following treatment. These issues may alter the ACL injury management decision, depending on the decision-making team's (which should include clinicians, the child and the child's parent/guardian(s)) risk tolerance.

Skeletal age assessment

Assessing and documenting the child's skeletal age, in addition to his or her chronological age, is necessary to individualising treatment of ACL injuries. The main goal with respect to skeletal age assessment is to define remaining knee growth. *Protecting the physis and perichondral ring from damage during ACL reconstruction is an important consideration*[45]—an insult to a growth area that is near completion of growth *can* result in premature closure.

> *'Estimating skeletal age and remaining growth are key considerations for treatment decision-making.'*

Estimating skeletal age and remaining growth are key considerations for treatment decision-making. These estimates will guide choice of treatment, timing of surgery and surgical method. Open physes in the child are vulnerable at surgery, and none of the current recommended surgical treatments for the child with an ACL injury can be guaranteed to protect the physis and avoid the potential complication of growth arrest or deformity (these risks are outlined below). The clinician might also consider long leg radiographs (hips to ankles) after injury to establish a baseline for assessing the potential development of angular deformity and leg length discrepancy. Assessing skeletal age is also relevant in research and may be beneficial for medicolegal reasons. If overgrowth, growth arrest or deformity occurs, presurgical documentation of skeletal age may be important (box 4).

Treating the child with ACL injury: to operate or not to operate?

Children who have repairable additional injuries at ACL injury diagnosis (eg, displaced bucket-handle meniscal tear) should be treated with early ACL reconstruction and meniscal repair.[77] In those without additional injuries warranting surgery, there are conflicting opinions regarding the best treatment approach. These approaches range from early ACL reconstruction for all

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children, to primary non-surgical management (high-quality rehabilitation alone) with the option of late ACL reconstruction if the child has recurrent instability problems despite high-quality rehabilitation or if he or she sustains secondary intra-articular injuries.

A well-performed ACL reconstruction and preservation of the meniscus can restore knee stability.[78] However, if the child receives inadequate (or no) rehabilitation, the chances of recovering high-level function to safely participate in all aspects of life (including pivoting sports), for the rest of his or her life, might be slim. Similarly, high-quality rehabilitation will not salvage poor surgical treatment (eg, graft malposition).

Children who undergo ACL reconstruction after failed non-surgical management may have a higher number of meniscal and chondral injuries at the time of ACL reconstruction compared with those who undergo early ACL reconstruction.[79–81] The number of instability episodes prior to surgery appears to be a more important factor than the length of time between injury and surgery.[82] This consideration is the background for early surgery decisions. However, there are a lack of high-quality, prospective studies investigating the outcomes of surgical and non-surgical treatment for paediatric ACL tears.[4]

> *'Non-surgical treatment is a viable and safe option in skeletally immature patients who do not have associated injuries or major instability problems.'*

Non-surgical treatment is a viable and safe treatment option in skeletally immature patients who do not have associated injuries or major instability problems.[83] High-quality rehabilitation alone may stabilise the knee dynamically without compromising the physes, and is a focused training program supervised by a qualified rehabilitation clinician (see *Section 3* for the key principles of high-quality rehabilitation). Non-surgical treatment can be a permanent treatment option for those who do not develop functional instability, or a short-term option to delay ACL reconstruction until the child has reached skeletal maturity. Abandoning non-surgical treatment in favour of ACL reconstruction is an option if the child has recurrent instability problems despite completing high-quality rehabilitation, or if the child has a secondary intra-articular injury. Therefore, clinicians must work together to closely and frequently monitor the child with repeated MRI and clinical examination as appropriate, being alert to instability episodes and secondary injuries that require prompt assessment and treatment.[82]

Risks associated with ACL reconstruction

Irrespective of the technique, surgical treatment of the ACL has inherent risks. Different ACL reconstruction techniques have different considerations to help avoid risk to the physes, articular surface and soft tissue structures of the knee. Here, we describe five key risks associated with surgical treatment for ACL injury of which clinicians, patients and their parents/guardians must be aware.

Risk 1: growth disturbance

Growth disturbances are a rare (approximately 2%)[43] but serious risk of ACL reconstruction. Growth disturbances may be a result of hardware, bone plugs at the physis, extra-articular tenodesis or use of over-the-top femoral position. Most of the growth in the child's lower extremities occurs from the physes of the distal femur and proximal tibia. Any surgical

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Box 4	Five considerations for skeletal age assessment

1. Understand the difference between skeletal age and chronological age.
2. Use imaging of the knee to determine if the femoral and tibial physes, and the tibial tubercle apophysis are open. If the growth areas are closed, then, independent of chronological age, the child can be treated as an adult.
3. None of the specific methods for skeletal age determination in isolation is sufficient to accurately determine skeletal age.
4. Use a multifaceted clinical approach to determine skeletal age that includes whether or not the child has had an adolescent growth spurt, the relative heights of the child's parents and Tanner staging.[74]
5. The most common method of skeletal age assessment is via posterior-anterior left hand and wrist X-ray. This can be compared with a skeletal atlas (eg, Gilsanz and Ratib[75] or Greulich and Pyle[76]) or using a smart-phone application (eg, the Bone Age app for iPhone).

procedures where tunnels are drilled through or near the physis are associated with a risk of growth arrest, and associated angular deformity and/or leg length discrepancy. Transphyseal techniques have a higher rate of graft rupture and a lower rate of lower limb deformity or axis deviation. Physeal-sparing techniques have a lower rate of graft rupture, and a higher rate of lower limb deformity or axis deviation.

Highly tensioned soft tissue grafts placed across femoral physes have been associated with limb length discrepancy and angular deformity.[84] Metaphyseal fixation techniques may pose an increased risk of femoral angulation and rotation relative to other techniques. Epiphyseal techniques may *increase* the risk of rotational deformity and *decrease* the risk of angular deformity.[85] Excessive growth may also be a problem, including symmetrical and asymmetrical overgrowth.[86]

Most patients with ACL rupture requiring surgical treatment are approaching skeletal maturity, and do not have substantial growth remaining. This means that angular deformities and limb length discrepancies are likely of relatively low clinical significance. Therefore, it may be reasonable to perform transphyseal procedures when the child has minimal growth remaining.

Regularly monitor the patient until skeletal maturity

Routine clinical and radiological follow-up within the first 12 postoperative months can help the surgeon detect early clinical and radiographic evidence of leg length discrepancy, angular deformity or and physeal injury. For the child with markedly open physes, appropriate follow-up evaluation of leg length discrepancy might include annual clinical assessment and knee radiographs with long-leg alignment views until skeletal maturity and physeal closure. Height should be monitored, and if growth exceeds 6 cm in 6 months, or if clinical findings warrant, the annual assessment should be brought forward.

Classifying growth disturbances

Growth disturbances can occur in several different forms (figure 9). The growth arrest may be due to:

► Localised physis injury resulting in a bone bridge leading to growth arrest and possible malalignment (type A);
► Overgrowth process potentially caused by hypervascularisation (type B);
► Undergrowth process arising from a graft traversing a physis under tension during growth and leading to a tethering effect (type C).

Risk 2: secondary ACL rupture

Young age, returning to pivoting sport and receiving an allograft are important predictors of new ACL injury after index ACL reconstruction.[58 87] One in four patients under 25 years *who returned to pivoting sports after ACL reconstruction* can be expected to sustain a new ACL injury (the pooled ipsilateral reinjury rate is approximately 10%; the pooled contralateral reinjury rate is approximately 12%).[88]

High rates of reinjury among young people with ACL reconstruction are concerning, although data regarding reinjuries among children with ACL reconstruction are sparse in comparison to data from skeletally mature patients. The best available evidence suggests a graft rupture rate in children and adolescents (age range 6–19 years) of 13%, and a contralateral ACL injury rate of 14%.[89] It is reasonable to hypothesise that high-quality rehabilitation with high adherence is likely an important step in reducing reinjury risk. The principles of rehabilitation for the skeletally immature patient are addressed in *Section 3*. The ACL graft is also affected by the status of the other ligaments, menisci, cartilage surfaces, limb alignment, rotation and the dynamic muscle control of these structures—all factors that must be considered during treatment decision-making.
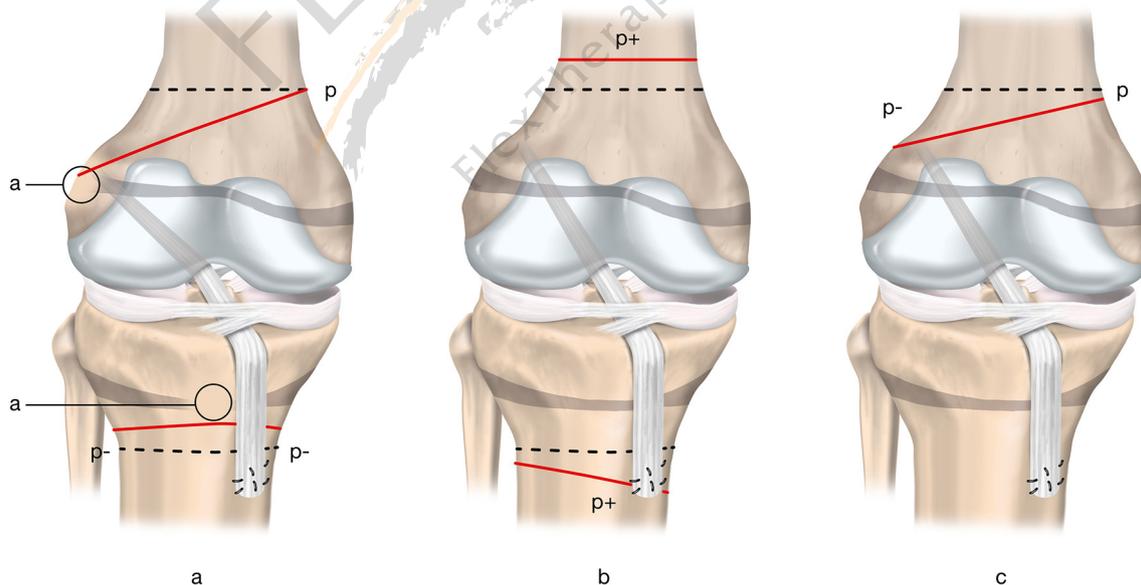

Figure 9 Three growth disturbances that may occur following ACL reconstruction. 'p' represents the physiological growth process; dashed lines represent the physiological growth arrest lines; continuous lines represent the observed pathological growth arrest line. Type A (arrest): growth arrest process (a) occurs after a localised injury to the physis and results in a bone bridge across the physis. The extent of deformity is proportional to the location and size of the initial physeal injury. Type B (boost): overgrowth process (indicated by p+) is probably caused by local hypervascularisation, stimulating the open physis (b). This growth disturbance is temporary and usually becomes apparent in a limited period of 2 years following ACL reconstruction. It primarily leads to leg length discrepancy. Type C (decelerate): undergrowth process (indicated by p–) due to a tenoepiphysiodesis effect (c). The graft tension across the open physis causes the deformity. Adapted from Chotel *et al*.[86]

Risk 3: poor long-term knee health

Meniscectomy is associated with an increased risk for osteo-arthritis.[90–92] Therefore, wherever possible, treatment of ACL injuries must emphasise preservation of the meniscus. Prior meniscectomy at the time of ACL reconstruction is associated with higher likelihood of chondral lesions, while prior meniscal repair is not associated with a higher likelihood of chondral lesions.[93] Because of the technical nature of performing ACL and concurrent meniscal surgery in smaller, younger patients with open physes, patients in whom meniscus repair is indicated should be treated by surgeons who (1) are experienced in treating patients with open physes and (2) perform a high volume of meniscal repairs.

Risk 4: knee stiffness

Knee stiffness may be due to the degree of injury to the ACL, disruption of the joint capsule and injury to structures other than the ACL. Knee stiffness may also be related to surgical interventions or inadequate rehabilitation. Knee stiffness is rare in children aged 13 years and younger, and less common in males and in those having surgery with an iliotibial band or hamstring autograft.[94] Patients who have knee stiffness following ACL injury should aim for full active knee extension range of motion prior to undergoing ACL reconstruction. If the knee extension deficit persists beyond 3 months postoperative, MRI to assess for anterior impingement (cyclops lesion) and subsequent arthroscopy (should the deficit continue to be unresolved despite focused rehabilitation attention) may be warranted.

Risk 5: infection

Data related to infection risks for paediatric patients are extrapolated from literature that combines paediatric and adult patients. Infection rates in adult patients are generally low for ACL reconstruction. The rate of deep infections after ACL reconstruction with autograft is 0.19%.[95]

Management of associated injuries

Here we address the key issues for managing cartilage and meniscal injuries in combination with ACL rupture, and the multiligament-injured knee.

Associated meniscus and cartilage injuries in children with ACL injuries

The degree of vascular penetration of the menisci declines with age, with between 10% and 30% of the menisci receiving vascular inflow in adults.[96] The more robust vascular distribution in the paediatric menisci is reflected by increased intrameniscal signal intensity on MRI. Globular and intrameniscal signal may be observed in children and may appear to be an intrasubstance meniscal tear. However, these findings are benign, and usually reflect the abundant vascularity of the paediatric menisci (figure 10).[97]

It is important to evaluate the MRI characteristics of the paediatric menisci to rule out meniscal injuries. In cases where the diagnosis is difficult, a diagnostic arthroscopy may be performed to clarify the diagnosis and ascertain the state of the meniscus. The clinician should also assess for a posterior medial meniscocapsular tear (ramp lesion).

'The clinician should also assess for a posterior medial meniscocapsular tear (ramp lesion).'

Figure 10 Appearance of the highly vascular paediatric meniscus of a boy aged 10 years on 3.0 T MRI (Signa HDxt 3.0T; GE Medical Systems).

Ramp lesions may be present in one in six adult patients with ACL injury, and the prevalence of ramp lesions in children with an ACL injury is similar to adults.[98] The surgeon should be vigilant to verify the presence or absence of a medial meniscal ramp tear by visualising the posteromedial compartment. Use a posteromedial knee arthroscopic portal, if necessary, to probe the posteromedial meniscocapsular junction. Ramp lesions may place more stress on an ACL reconstruction if the lesion is not concurrently repaired.[99]

'Meniscal repair should be performed whenever possible'

Meniscal repair should be performed whenever possible in the paediatric patient because of the deleterious effects of meniscectomy and the positive outcomes of meniscal repair (ie, the improved healing potential of the meniscus).[79 100 101] This is especially important for bucket-handle, root and radial meniscal tears and ramp lesions. If the surgeon does not have the skills or equipment to repair the meniscus tear, he or she should consider referring to a surgeon who has the expertise and equipment. Early diagnosis and appropriate treatment of ACL injuries and meniscus tears is needed to provide the best chance of preserving meniscal tissue.

Articular cartilage injuries in combination with ACL injury are less common than meniscal tears.[79] However, the clinician should have a higher degree of suspicion of articular cartilage injury in patients with combined ACL and meniscal injuries.[102] The medial femoral condyle may be particularly vulnerable.[102] Factors that may be associated with more severe chondral lesions are recurrent instability episodes and increased time between ACL injury and reconstruction.[80 102 103] It is unclear whether non-surgical management of ACL injuries is associated with a higher incidence of new chondral and meniscal lesions than ACL reconstruction.[104]

Associated ligament injuries in children with ACL injuries

There is limited research on multiligament knee injuries and treatment in paediatric patients, and these injuries are less common in children than in adults.[105] Therefore, consider referral to a specialist centre.

Specific surgical treatment considerations
Combined ACL and fibular collateral ligament injuries

Use fluoroscopy prior to placing suture anchors for a repair, or for tunnel reaming for a concurrent ligament reconstruction, to evaluate tunnel position in relation to the physes.[106]

Combined ACL and posterior cruciate ligament injuries

Non-surgical treatment may be appropriate for partial posterior cruciate ligament (PCL) tears or non-displaced avulsion injuries. PCL reconstruction is a relatively safe and viable treatment option in patients with multiligament injuries.[107] Using a tibial inlay technique with a modified femoral tunnel location avoids transphyseal drilling,[108] although there are no high-quality studies of this technique in children.

True knee dislocation

Perform a reduction by manipulating the tibia relative to the femur. Avoid forceful hypertension or rotation, to minimise the risk for damage to cartilaginous and/or neurovascular structures. Following reduction, a dynamic knee brace can be applied (for at least 12 weeks) to prevent further intra-articular damage and to help hold the knee reduced[109] while further treatment is planned. Ultimately, reconstruction of the ACL and PCL in combination with repair/reconstruction of additional ligaments (as needed) is the appropriate treatment.

Section 5: paediatric patient-reported outcome measures

This section addresses the fundamental clinical question: *how does the clinician measure outcomes that are relevant to the child with an ACL injury?* Assessing patient-reported outcome measures (PROMs) provides insights into aspects of the patient's function that cannot be evaluated with clinical tests or imaging.[110] Because of this, evaluating PROMs is important when managing the child with an ACL injury, and when conducting research in this field.

Valid outcome instruments must have appropriate measurement properties, including reliability, validity (content, criterion and construct) and responsiveness. Instruments that were developed for adults may not be valid for children and adolescents. Paediatric patients have different levels of comprehension (this age group includes a spectrum of comprehension abilities from younger children to older adolescents) and interpretation of instruments. Most importantly, paediatric patients may value different outcomes when evaluating their knee function, and instruments must reflect the issues that are important to children and adolescents.

Paediatric PROMs should be either developed or specifically validated in this population. The process of validation should include an assessment of comprehensibility, reliability, validity and responsiveness. Child-reported outcome assessment is typically valid in older children and adolescents (aged >10 years).[111] In younger children (aged <10 years), parent-proxy-reported outcome assessment may be more appropriate. However, there is potential for bias with proxy-reported outcomes.[112]

Paediatric PROMs (table 2) must be valid for children and adolescents with ACL injury. However, a paediatric-derived PROM is not currently available. Such an instrument would

Table 2 Summary of appropriate PROMs for the child with ACL injury

Type of instrument	Scale
Health-related quality of life	Child Health Questionnaire[128] PedsQL[129] Pediatric PROMIS[130]
Condition-specific or region-specific	Pedi-IKDC[131] KOOS-Child[132]
Activity level assessment	Pediatric Functional Activity Brief Scale[133]

IKDC, International Knee Documentation Committee; KOOS, Knee Injury and Osteoarthritis Outcome Score; PROM, patient-reported outcome.

ensure the items covered issues that matter most to children and adolescents. The Pedi-IKDC and KOOS-Child were adapted from adult PROMs designed to assess self-reported knee function. The Pedi-IKDC has been correlated to the International Knee Documentation Committee subjective knee form—providing preliminary evidence of construct validity.[10 11] Given that patients with a history of ACL injury may develop symptoms and signs of osteoarthritis within 10 years of the index injury,[5] and the relationship between symptomatic osteoarthritis and poor quality of life,[3] assessing quality of life and long-term knee function outcomes using valid PROMs may also be important.

Recommendations for using PROMs in clinical practice with paediatric patients:
- ▶ Use a generic measure of health-related quality of life;
- ▶ Use either the Pedi-IKDC or KOOS-Child to assess self-reported knee function;
- ▶ Use the Pediatric Functional Activity Brief Scale to assess self-reported activity level.

In research, it may be appropriate to include other PROMs depending on the research question. Researchers need to make decisions about the most appropriate outcome(s) when planning their study.

Section 6: ethical considerations

This section addresses the fundamental clinical question: *what are the clinician's role and responsibilities?* Treatment decisions that involve children are among the most difficult decisions the clinician faces, especially when scientific knowledge is limited. Striking a balance between ethical principles can be especially challenging when there is a conflict of opinion. In this section, we outline the relevant ethical considerations for the clinician who treats children with ACL injuries.

It is impossible to provide specific ethical guidance that applies to all sporting injuries in adolescents and children, given the varying individual circumstances. However, it is incontrovertible that it is in the best interests of all children not to have knee and associated injuries. Therefore, injury prevention programs are fundamental to the best interests of the child. Clinicians have an obligation to support policies and practices that encourage coaches, teams/clubs and (inter)national federations to prioritise injury prevention. All parties should be committed to protecting the long-term welfare of the growing child. Nevertheless, there may be exceptional cases where parents/guardians may, with the approval of their child, rationally prioritise short-term goals. One example could be that, despite inherent risks for reinjury, an early return to sport might be a high priority for a child who has exceptional talent in a given sport.

Protecting the integrity of the knee should be the clinician's primary focus. Decisions regarding how to protect the integrity of the child's knee must be shared between the child, parent/guardian (surrogate decision maker) and clinician.[113] Parents have an obligation to care for their children, and bring them up

to live good lives.[114] Nevertheless, parents have different perceptions of what constitutes 'good living'.[115] Most ethicists agree that parental influence is a positive thing.[116] However, in high performance children's sport, parents and coaches can pressure the child and clinician to focus on short-term athletic goals at the expense of long-term welfare.[117]

Issues related to consent and obtaining consent for treatment

Children are a vulnerable population.[118 119] In the context of treatment of ACL injury, the child is doubly vulnerable given his or her developing, but uncertain, life plans[120] and developmental stage. We can never be certain of all of the risks to normal development of the individual child.[121] It is difficult to gain legally legitimate informed consent from children in the treatment decision-making process. Therefore, the clinician needs to act as a cofiduciary on behalf of the child, while parents give consent.[122]

The clinician and/or parent(s) are obliged to serve the interests of the child above all other interests.[122 123] This is what is meant by having a fiduciary duty to the patient. The clinician must talk with both the child and the surrogate decision makers in ways that are respectful of, and comprehensible by everyone involved.[124] In addition to avoiding conflicts of interest, the clinician must always seek the approval or assent of the child, irrespective of the parents/guardians wishes, at a communication level that matches the child's competence.[125] The child should be present in all discussions concerning him or her, to respect his or her (emerging) autonomy.[126]

Arriving at a shared decision

There should be consensus between all parties when arriving at a decision. This consensus should be based on realistic assessments of risks and benefits and a proper consideration of the goals of the child and parent. The clinician's responsibility is to guide this discussion with accurate information from the best quality research. There are several ethical standards that can help the clinician, child and parent(s) navigate the decision-making process, and arrive at ethically justified treatment decisions.

Some paediatric ethical standards are not identical—some aim at higher thresholds, while others accept a lower threshold of justification. There are six standards that can be helpful in different clinical scenarios in paediatric ACL injury (box 5).

Box 5   Six standards that can be helpful in different clinical scenarios in paediatric ACL injury

1. Best interests[134]: widely used, but it is difficult to predict what is in the best long-term interests of a child.
2. Harm principle[135]: a threshold below which the clinician *should not* acquiesce to parent-led decision, so that the child is not harmed.
3. Parental discretion[136 137]: parent-preference is accepted because it is not sufficiently harmful to the child for the clinician to dissent from the parent(s') choice.
4. Costs/benefits[138]: involves risk assessment, but its application to the child means that the clinician may need to compare very different kinds of futures that may or may not eventuate.
5. Not unreasonable[139]: focuses only on the appropriateness of decisions and decision maker(s).
6. Reasonable choice[140]: a decision method that attempts to incorporate the previous five standards into a single model or intervention.

The clinician has an important role in treatment decision-making, because he or she typically has superior knowledge of treatment options, risk and benefits than children and parents. To best guide the child and his or her parent(s), the clinician must have a clear idea of the range of interventions that are (1) optimal, (2) acceptable and (3) not desirable, and be able to justify this with reference to the best quality research and clinical experience. In many healthcare settings, parent(s) take responsibility for the ACL treatment decision, commensurate with the child's assent. Where there is a lack of consensus in the decision-making process (eg, the parent decides for something that is not recommended by the clinician), the clinician may also consider whether he or she can defend a treatment recommendation based on one of the six ethical standards.

Section 7: future research

Management of paediatric ACL injuries is strongly debated. Reflecting some of the concern and controversy is a high ratio of clinical commentaries and narrative reviews to original articles on this topic. The problem for the clinician is that there is scarce high-quality evidence that he or she can look to, to help him or her best manage paediatric ACL injuries. The scientific literature is inconsistent and limited by inferior methods that carry a high risk of bias.[4 127] There are no randomised trials comparing different treatment approaches or different surgical techniques. Most of the publications have only short-term follow-up; there are none with follow-up beyond 10 years. Therefore, long term knee-health (including osteoarthritis) and quality of life is unknown.

METHODOLOGICAL CONSIDERATIONS

There are five key issues that must be addressed by future studies:

1. Most clinical studies on paediatric ACL injury are of cross-sectional or retrospective design, the study populations are often at high risk of selection bias and include small samples. This means there is a high risk that existing research does not reflect the typical paediatric patient with an ACL injury.
2. Many studies do not provide adequate descriptions of the treatments that the patients have received, and patient adherence has not been reported. A meaningful interpretation of study outcomes is only possible with a detailed description of the surgical technique, rehabilitation, brace usage, return to sport clearance and recommendations of activity modification.
3. Many studies fail to assess the skeletal age of included participants, and few report the remaining growth of participants. Chronological age alone is an unreliable indicator of skeletal maturity. Because of this, it is difficult to know to which skeletal age group these research results apply.
4. Patients aged up to 18 years are often included in paediatric studies. This is a problem because it is likely that the patient population is a mix of skeletally mature and immature patients. Therefore, the literature may be biased towards the older patients. Having mixed populations also complicates pooling or comparing results from skeletally immature patients across studies.
5. Knowledge of preinjury and post-treatment activity level gives important insight into a key risk factor for injury. The greater exposure a child has to potentially injurious situations (eg, playing pivoting sport), the greater the chance of (re)injury. Activity level is a key confounding factor that is

rarely accounted for in statistical analyses. This means there is a risk that estimates of secondary injury incidence may be overestimated or underestimated in comparisons between studies or patient-groups.

RESEARCH PRIORITIES

There are four research priority areas to improve prevention and outcomes of paediatric ACL injury:

1. Prospective injury surveillance studies to identify injury mechanisms and modifiable risk factors for ACL injury, combined injuries and knee reinjuries.
2. Prospective research on outcomes after surgical and non-surgical treatment. Long-term follow-up (beyond 10 years) is essential to answer key questions of how an ACL injury in childhood impacts physical activity, future knee-health and quality of life.
3. Research on the efficacy of different surgical techniques and characteristics (eg, timing of surgery, graft types), and high-quality rehabilitation programmes, knee brace usage and activity modification after injury and surgery.
4. Multicentre and registry studies should be prioritised. Because of smaller numbers of ACL injuries in paediatric patients than in skeletally mature patients, specialist treatment centres, expert clinicians and researchers must prioritise collaboration.

IN MEMORY OF DR ALLEN F ANDERSON

An excellent clinician-scientist and a keen coworker in this project, Allen F Anderson, MD, died in a farming accident on Sunday, 12 November 2017. This tragedy occurred shortly after he had been an active participant in this IOC consensus meeting on the topic of his life-long clinical and research passion, paediatric ACL injuries.

Born on 16 November 1949, Dr Anderson was a graduate of the University of Tennessee College of Medicine. He completed a residency in orthopaedics at Vanderbilt University and was board-certified by the American Board of Orthopaedic Surgery in general orthopaedics, with a certificate of added qualification for Sports Medicine.

Dr Anderson was a sports medicine specialist with an interest in knee injury and ligament reconstruction, and with special interest in children's injuries. He published more than 100 peer-reviewed journal articles and 26 book chapters, and received a patent for the invention of a paediatric ACL reconstruction system. Among numerous awards, three standouts were: being recognised as one of America's Top Physicians 2004–2012 from Consumer's Research Council, being elected to Best Doctors in America by his peers 2007–2008 and being Nashville Business Journal Top Doctor 2016–2017.

Dr Anderson had many prestigious positions through his life. He served as President of the American Orthopaedic Society for Sports Medicine from 2015 to 2016, and as an Associate Editor of *The Orthopedic Journal of Sports Medicine* and *The American Journal of Sports Medicine*.

Above all, he was a true friend and colleague whom you could go to with problems and challenges, not the least among our youngest patients. Allen will be greatly missed by us all.

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The Effectiveness of Injury Prevention Programs to Modify Risk Factors for Non-Contact Anterior Cruciate Ligament and Hamstring Injuries in Uninjured Team Sports Athletes: A Systematic Review

Abstract

Background

Hamstring strain and anterior cruciate ligament injuries are, respectively, the most prevalent and serious non-contact occurring injuries in team sports. Specific biomechanical and neuromuscular variables have been used to estimate the risk of incurring a non-contact injury in athletes.

Objective

The aim of this study was to systematically review the evidences for the effectiveness of injury prevention protocols to modify biomechanical and neuromuscular anterior cruciate and/or hamstring injuries associated risk factors in uninjured team sport athletes.

Data Sources

PubMed, Science Direct, Web of Science, Cochrane Libraries, U.S. National Institutes of Health clinicaltrials.gov, Sport Discuss and Google Scholar databases were searched for relevant journal articles published until March 2015. A manual review of relevant articles, authors, and journals, including bibliographies was performed from identified articles.

Main Results

Nineteen studies were included in this review. Four assessment categories: i) landing, ii) side cutting, iii) stop-jump, and iv) muscle strength outcomes, were used to analyze the effectiveness of the preventive protocols. Eight studies using multifaceted interventions supported by video and/or technical feedback showed improvement in landing and/or stop-jump biomechanics, while no effects were observed on side-cutting maneuver. Additionally,

multifaceted programs including hamstring eccentric exercises increased hamstring strength, hamstring to quadriceps functional ratio and/or promoted a shift of optimal knee flexion peak torque toward a more open angle position.

Conclusions

Multifaceted programs, supported by proper video and/or technical feedback, including eccentric hamstring exercises would positively modify the biomechanical and or neuromuscular anterior cruciate and/or hamstring injury risk factors.

Introduction

Hamstring strain (HAM) and anterior cruciate ligament (ACL) injuries are, respectively, the most prevalent [1] and serious [2] non-contact occurring injuries in team sports and therefore preventive programs aiming to protect athletes from both types of injury should be integrated. Several injury prevention programs involving jumps [3], strength [4–7], unstable [8,9], or a combination of different exercises modes [10–13] have been proposed to prevent both ACL and HAM injuries. However, there is still a lack of uniform criteria regarding the design of an ideal protocol for effective protection against the two aforementioned injuries in team sport athletes. Indeed, to the authors' knowledge there is no consensus about how to integrate ACL and HAM preventive exercises within an optimal injury prevention protocol in team sports. A recently published systematic review highlights the lack of enough evidence to support the effect of neuromuscular training programs to reduce ACL injuries in athletes [2]. Additionally, it seems that multifaceted programs involving strength, plyometric, balance, agility, core, and flexibility exercises would be the most effective intervention to prevent from ACL injuries [2]. Similarly, effective strategies to reduce the incidence of HAM injuries may also include a combination of different types of muscular actions including both active lengthening eccentric and co-contracting knee stabilizer exercises [1,14].

In previously uninjured athletes the protective effects of different prevention protocols have been assessed by their capacity to modify biomechanical (posture, trunk, or lower limb alignments) and neuromuscular (strength deficits or balance) risk factors, rather than to reduce injury rates (the later require more time and also only can be accomplished through a prospective study). For example, knee valgus or varus moment and open knee flexion angle during landing, exaggerated hip internal rotation and adduction, and/or an uncontrolled trunk motion including lateral displacement during jumping [12,15], or cutting maneuvers [16] have been associated with an increased ACL injury risk in females athletes. On the other hand, the angle at which the optimal knee flexor peak torque occurred has been used to assess the risk of HAM injury [17]. Furthermore both ACL and HAM injuries have been associated with hamstring strength, hamstring-to-quadriceps strength ratio or hamstring bilateral ratio [18]. Even though the above-mentioned variables have been the focus of several trials [1,2,19], there is still a lack of consensus about how these factors would respond to different training interventions. For example, when strength training exercises were used alone, including closed-chain hip rotation, bands, machine and free weight lower body exercises, studies reported no change [5] to significant modifications [20] in the hip internal rotation, and knee abduction moment during running or cut and jump actions. Furthermore, significant increases in isometric hamstring strength in response to similar eccentric exercise protocols have been produced with [21] or

without [22] a concomitant displacement of the optimal knee flexion peak torque toward a more open angle position.

To the authors' knowledge there are still no standardized guidelines for designing an effective lower limb injury prevention protocol in terms of exercise modes (stable, balance, open or closed chain, using eccentric or concentric actions), sets, repetitions and relative overload in team sport athletes. Therefore, the aim of the current review is to examine the documented effects of the different proposed injury prevention protocols on the following modifiable ACL and/or HAM risk factors in uninjured team sport athletes: i) knee valgus/varus angle and moment; ii) hip adduction/abduction angle and moment; iii) knee and hip rotation angle; iv) knee and hip flexion angle; v) hamstring and quadriceps muscle strength; vi) hamstring to quadriceps (H/Q) conventional and functional strength ratios; and vii) the angle at which the optimal knee flexor peak torque occurred.

Method

A systematic review of the literature was conducted in accordance with the PRISMA guidelines (S1 Table) [23,24] with procedures defined a priori. Search of literature was performed by using PubMed, Science Direct, Web of Science, Cochrane Libraries, U.S. National Institutes of Health clinicaltrials.gov, Sport Discuss and Google Scholar, from the start date of the representative database through the last week of March 2015. English-language publications in human populations were identified as being eligible for review. Articles were included if they were published in peer reviewed journals and full text was accessible. Commentaries, reviews, or duplicate publications from the same study were removed. Manual searches of personal files were conducted, along with screening of reference lists of previous reviews and identified articles, for inclusion. Combinations of the following keywords were used as search terms: "Anterior cruciate ligament or ACL and injury"; "hamstring and injury or strain", together with the markers "exercise", "intervention", "training", "protocol" "prevention" "muscle", "biomechanics", "kinetic", and "kinematic".

The selection criteria were applied independently by two reviewers (AM and FN). Potentially relevant articles were selected by: 1) screening the titles; 2) screening the abstracts; and 3) if abstracts did not provide sufficient data, the entire article was retrieved and screened to determine whether it met the inclusion criteria depicted in Table 1.

The abstracts of the search results were reviewed. Reference lists of relevant studies were also reviewed to identify publications not found through the electronic search. Only studies examining the effect of injury prevention protocols on some of the previously identified HAM and/or ACL injury risk markers were considered. When data were not accurately presented (only available from figures or graphs) authors were contacted and requested to provide the appropriate range of values.

The following qualitative and quantitative information was extracted from each included study: authors; publication year; baseline population characteristics; intervention and control

Table 1. Study Criteria for Inclusion in the Review.

Intervention studies
Duration of at least 4 weeks involving minimum of 8 training sessions no longer than 35 minutes
Examined at least one of the previously defined lower extremity injury risk factors
Involves male and/or female athletes (an athlete was defined as a person who performs minimum of two organized training sessions per week).
Participants: ≥14 years old, team sport athletes,
Without history of an ACL and/or hamstring injury, not engaged in any injury prevention program over the last 12 months prior to the intervention

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procedures; study duration; sample size per group; training modalities, number of exercises, sets, frequency and total time per session; outcomes measured at pre- and post-intervention; group means and SDs for the following variables: quadriceps and hamstrings strength; hip and knee flexion and extension moments; hip initial flexion and abduction angles; hip peak flexion and abduction angles; hip maximum external rotation angle; knee peak valgus moment; knee external rotation moment; knee Peak internal-rotation moment; knee initial flexion angle; knee peak flexion angle; knee valgus angle; optimal knee flexion peak torque localization; optimal knee extension peak torque localization and conventional and functional H/Q. In order to analyze the observed results using comparable assessment methods, the information was organized into four categories: i) landing, ii) side cutting, iii) stop-jump, and iv) muscle strength.

Methods of the analysis and inclusion criteria were specified in advance, and documented in a protocol registered at the International prospective register of systematic reviews, PROSPERO (CRD42015028041).

Methodological assessment and risk of bias

Two reviewers (AM and FN) ascertained individual study information independently as part of the quality control process. The methodological quality of the included studies was assessed based on criteria adapted from Downs and Black [25]; Kennelly [26] and Physiotherapy Evidence Database (PEDro) scale: 1) clearly described the aim/hypothesis/objective; 2) participants free of previous knee/hamstring injury; 3) groups at baseline similar (sex, age and activity/sport); 4) clearly described characteristic of the participants; 5) clearly described Inclusion/exclusion criteria; 6) main outcome clearly described; 7) replicable (clearly described intervention protocol); 8) clearly presented results; 9) reported actual probability value for the main outcomes (e.g. 0.035 rather than <0.05); 10) staff, places and facilities where the participants were treated, representative of the treatment of the majority of the population; 11) availability of control group; 12) blinded researcher measuring the outcomes of the intervention; 13) patients from different intervention groups recruited over the same period of time; 14) randomized study; 15) incompliance reported; 16) reliability of outcomes. For each item, each study could be scored either 1 or 0 points. If the item was not applicable or not reported in the study, 0 points were recorded. For each study, the total quality assessment scored ranged from 0 to 16. Higher quality assessment number indicated a better methodological approach.

Statistical analysis

From the collected data, we used the pre and post values of mean, standard deviation (SD), and sample size. The effect size was calculated using the Hedges' g.

Result

After removing the duplicates, 4801 records were found through three electronic databases. Title and abstract selection excluded 4370 and 354 records, respectively. The remaining 77 records were reviewed based on exclusion/inclusion criteria and 56 studies were rejected for different reasons (Fig 1 and S2 Table). One of the reviewed studies was excluded because of using selective participants (high-risk vs. low-risk athletes) [27]. Another study was also excluded because of unclear intervention protocol [18]. Thus a total of 19 studies were included (Fig 1).

The scores for the methodological quality assessment ranged from 9 to 15 and the mean was 12.2 (Table 2).

The total number of participants in all included studies was 485, comprising 285 female and 200 male. The included articles used different protocols involving resistance [6], eccentric [30,35], or plyometric exercises [3] alone or combined with other exercise modalities
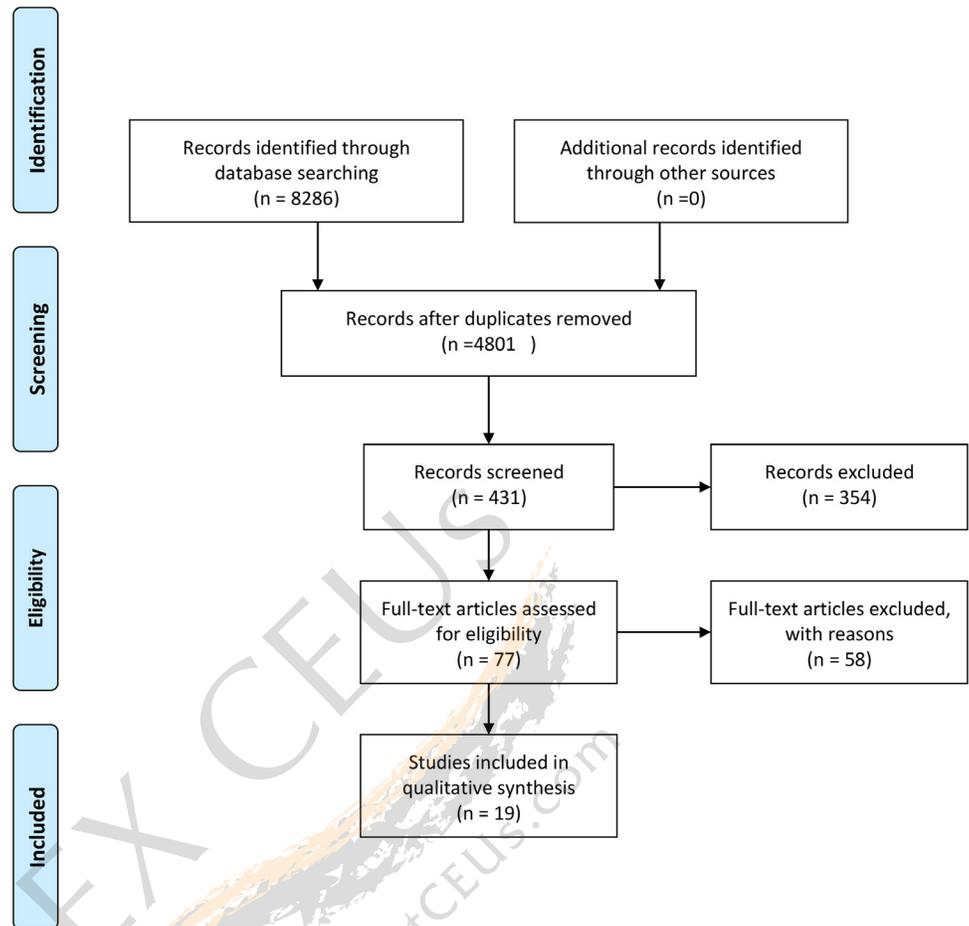
Fig 1. Flow diagram of article selection according to PRISMA.

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[7,28,29,31,33,34,36,38–40] supported by video feedback [32] and/or technical corrections [8,11,37,41].

Two studies analyzed the effects of the applied interventions to modify some of the afore-mentioned risk factors during landing and stop-jump [3,29]; three studies considered landing and muscle strength outcomes [11,33,38]; one study evaluated stop-jump and muscle strength outcomes [6]; the rest of studies focused on a single test-task: landing [37,39]; stop-jump [32]; side cutting [8,40,41]; and muscle strength outcomes. [7,28,30,31,34–36]

Table 3 summarizes the type of intervention, main characteristics, and effects of the all-19 included studies.

Landing

Seven studies including only female participants, n = 143 (77 basketball and 66 soccer players) used plyometric combined with other exercise modalities (balance, strengthening and flexibility) to analyze the effects of injury prevention programs on kinematic and kinetic variables during landing [3,11,29,33,37–39]. Three studies analyzed a 30 cm drop vertical jump (DVJ) [3,29,39], two a vertical jump (VJ) [11,33], and the other two a 30 to 33 cm singled leg drop jump (SLD) [37,38]. The averaged quality of these studies was 11.5, ranging from 9 to 14, with 1 study scoring 14 (out of 16). Interventions lasted from 5 to 16 weeks.

Table 2. Quality assessment of the included studies.

Study	Quality score	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Brughelli et al. [28] 2010	13	1	0	1	1	0	1	1	1	0	1	1	1	1	1	1	1
Chappel and Limpisvasti [29] 2008	9	1	0	0	1	1	1	1	1	1	1	0	0	0	NA	1	0
Clark et al. [30] 2005	10	1	1	1	0	1	1	1	1	1	1	0	0	1	NA	0	0
Daneshjoo et al. [31] 2012	13	1	1	1	1	0	1	1	1	0	1	1	1	1	1	0	1
Donnelly et al. [8] 2012	13	1	1	1	1	1	0	1	1	0	1	1	1	1	0	1	1
Herman et al. [6] 2008	14	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1
Herrington [3] 2010	12	1	1	1	1	1	1	1	1	1	1	0	0	1	NA	0	1
Holcomb et al. [7] 2007	12	1	1	1	1	1	1	1	1	1	1	0	0	1	NA	0	1
Kato et al. [32] 2008	13	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0
Lephart et al. [33] 2005	12	1	1	1	1	1	1	1	0	1	0	0	0	1	1	0	1
Lim et al. [11] 2009	13	1	1	1	1	1	1	1	1	0	1	1	0	1	1	0	1
Mendiguchia et al. [34] 2014	15	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1
Mjølsnes et al. [35] 2004	14	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1
Naclerio et al. [36] 2013	14	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	1
Nagano et al. [37] 2011	11	1	1	1	1	1	1	1	1	0	1	0	0	1	NA	0	0
Ortiz et al. [38] 2010	10	1	0	1	0	0	1	1	0	0	1	0	1	1	1	1	1
Pollard et al. [39] 2006	12	1	1	1	1	1	1	1	1	1	1	0	0	1	NA	1	0
Wilderman et al. [40] 2009	13	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0
Zebis et al. [41] 2008	9	1	0	1	1	0	1	0	1	1	1	0	0	1	NA	0	1

Note: NA: not applicable; Quality score criteria are explained in the methodological assessment and risk of bias section.

Knee flexion angle increased after performing mixed interventions combining strength-balance and plyometric exercises [29,33,37] or following a program aiming to improve technique [11]. Conversely, no significant changes on knee flexion angle have been reported after performing both a 6-week [38] or a 16-week [39] mixed protocol in female soccer players.

Knee flexion moment was decreased in two studies where the intervention protocols involved active feedback aiming to improve the correct execution of selected balance exercises [29,33]. Only one study involving a 4-week progressive jump training reported significantly decreased and large effect sizes in valgus angle during landing [3], while no changes were observed by other 4 studies in which multifaceted interventions including plyometric, strengthening and balance exercises were implemented [29,37–39].

Side-Cutting

Three studies involving 84 athletes (34 male and 50 female) analyzed the effectiveness of different injury prevention protocols to modify knee biomechanics during side-cutting maneuvers [8,40,41]. The mean quality score was 11.5, ranging from 9 to 13 (out of 16). Interventions lasted from 6 weeks to 12 months.

Two studies investigated 45° pivoting [8,40] and the other study did not report the pivoting angle [41]. All three studies focused on knee flexion angles and moments. The prevention programs varied between studies from a progressive agility exercise protocol [40] toward a combination based on feedback protocols including balance, plyometric and agility exercise, [8] and a proprioceptive-balance program [41]. The applied interventions did not increase knee flexion angles and moments measured during cutting maneuver. Two studies examined the effect on vertical ground reaction forces, but again interventions did not alter this variable when performing either pre-planned[8,40] and unplanned sidestepping actions [8].

Table 3. Summary of the main characteristics and relevant finding of the 19included studies.

Study	Assessment	Participants	Design and type of intervention	Length	Relevant findings
Chappel and Limpisvasti [29] 2008	Landing (DJ) and stop jump	Female (n = 30; 19 ±1.2 y) basketball (n = 18) and soccer (n = 12) players	Controlled within participants pre-post comparison. Ten exercises involving core, strengthening, dynamic joint stability and balance training, jump training, and plyometric exercises. With proper technical feedback, daily 10 to 15 minute workout.	6 wk	From DJ: ↓HIAbdA (g = -0.44); ↑KIFA (g = 0.54); ↑KPFA (g = 0.54); ↓KFM (g = -0.46) From stop jump: ↓HIFA (g = 0.68); ↓HMxERA (g = -0.52); ↓KERM (g = -0.26); ↓KPVM (g = -0.38) ↓KFM (g = -0.21)
Herrington [3] 2010	Landing (DJ) and stop jump	Female basketball players (n = 15; 19.1 ±6.1 y)	Controlled within participants pre-post comparison. Progressive jump training from bilateral to unilateral activities with proper feedback and technical corrections, 3-day per week 15 min session.	4 wk	↓ KVA at both limbs: DJ (left g = 1.54; right g = 1.74) and Stop Jump (left g = 0.73; right g = 0.54)
Lephart et al. [33] 2005	Landing (VJ) and muscle strength (isokinetic)	Female basketball or soccer players (n = 27; 14.3±1.3 y)	Two PG, randomized pre-post comparison. Weeks 1st to 4th: Resistance flexibility and balance exercises for both groups. Weeks 5th to 8, different interventions 1) Plyometric + agility (P, n = 14) 2) Basic resistance + flexibility + balance exercises (B, n = 13), 3-day per week 30 min session programme supported with verbal and video feedback.	8 wk	Both groups (P and B): ↑QS at 60°/s-1 and 180°/s-1 ↑HIFA (P g = 1.08; B g = 0.24) ↑KPFA (P g = 0.92; B g = 0.42); ↓HFM (P g = -0.26; B; g = 0.17) ↓KFM (P g = 0.61; B g = -0.69) P group only: ↑HPFA (g = 0.77)
Lim et al. [11] 2009	Landing (RVJ) and muscle strength (isokinetic)	Female basketball players (n = 22; 15 to 17 y)	Two PG, randomized pre-post comparison. 1) Experimental (E, n = 11) Modified version of Mandelbaum's Prevent Injury and Enhance Performance (PEP) Programme involving stretching, strengthening, plyometric and agility exercises supported by technical corrections. Daily 20 min session. 2) Control (C, n = 11) only regular training	8 wk	E group to pre and to C: ↑KPFA (g = 0.41); ↑KFM (g = 0.41); ↓KPEM (g = -0.95); ↓KVM (g = -0.69) ↓QS and ↑H %EMG (g = 0.84)
Ortiz et al. [38] 2010	Landing (SLDJ) and muscle strength (isometric)	Female soccer players (n = 30, 14 to 15 y)	Two PG, randomized pre-post comparison 1) Experimental (E, n = 14): Flexibility, strengthening and plyometric exercises 2) Control (C, n = 14) continue its regular practice and games. Two days/week, 20 to 25 min workout.	6 wk	From SLDJ: ↑KPEM; ↑ KPVM; NS = between groups ** ↑QS E group to pre and to C
Nagano et al. [37] 2011	Landing (SLDJ)	Female basketball players (n = 8, 19.4 ±0.7 y)	Controlled within participants pre-post comparison Plyometric, balance exercises and specific basketball skills (first 3-weeks focused to improve landing technique). Three days/week, 20 min workout.	5 wk	↑ KIFA (g = 2.21)
Pollard et al. [39] 2006	Landing (DJ)	Female soccer players (n = 18, 14 and 17 y)	Controlled within participants pre-post comparison. Prevent injury and enhance performance protocol involving flexibility, strengthening, plyometric and agility exercises supported by video feedback. Three days/week, 20 min session.	16 wk	↓HIRA (g = -0.71); ↑HPAbdA (g = -0.64)
Donnelly et al. [8] 2012	Side-cutting (planned and unplanned)	Males Australian football players (n = 34, >19 y)	Two PG, pre-post comparison. 1) Experimental (E, n = 14) balance, plyometric, agility exercises supported by feedback and technical corrections. 2) Contrast shadow training (ST, n = 20). Both groups trained 2 days/week, 20 min session first 18 weeks and 1 day/week from 17th to 28th week.	28 wk*	Both E and ST: ↓KPIRM for planed side cutting (g = -0.57); ↑KPVM for unplanned side cutting (g = 0.44).
Wilderman et al. [40] 2009	Side-cutting	Female basketball players (n = 30, 21.1 ±2.8 y)	Two PG, randomized pre-post comparison 1) Experimental (E, n = 15), progressive agility training program. Four days/week, 15 min session 2) Control (C, n = 15) no specialized agility training.	6 wk	Both E and C. No change in knee kinematic; ↑MH (g = 0.94); ↓VM (g = -0.49) activation during ground contact phase

Table 3. (*Continued*)

Study	Assessment	Participants	Design and type of intervention	Length	Relevant findings
Zebis *et al*. [41] 2008	Side-cutting	Female (n = 20, 26 ±3 y) handball (n = 8) and soccer (n = 12) players.	Controlled within participants pre-post comparison. Neuromuscular training with technical support to improve awareness and neuromuscular control during landing, cutting and jumping with simultaneous ball handling. Two days/week, 20 min workout	12 months	NS in knee and hip kinematic ↑ST and NS in Q activation
Herman *et al*. [6] 2008	Stop Jump and muscle strength (isometric)	Female recreational team sport athletes (n = 66, 18 to 30 y)	Two PG, randomized pre-post comparison. 1) Experimental (E, n = 33), strengthening exercise using resistance bands and balls. Three days/week, 45 min session. 2) Control (c, n = 33) no strength training.	9 wk	E group to pre and to C
Kato *et al*. [32] 2008	Stop Jump	Female basketball players (n = 20; 20.4 ±1.0 y)	Two PG, randomized pre-post comparison 1) Experimental (E, n = 10) Strengthening, jump-landing and balance exercises supported by feedback and technical corrections. Three days/week, 20 min session. 2) Control (C, n = 10) no intervention.	4 wk	E group to pre and to C ↓KVA (g = -1.50)
Naclerio *et al*. [36] 2013	Muscle strength (isometric)	Male professional soccer players (n = 20, 23.8±3.1 y)	Two PG randomize pre-post comparison. 1) E experimental (E, n = 10), strengthening eccentric and balance exercises. Performed 3 day/week 15 min session 2) control (C, n = 10) no intervention.	4 wk	E group to pre and to C; ↑H isometric PT at 800 (g = 0.78) and 35°(g = 0.50) knee angles
Brughelli *et al*. [28] 2010	Muscle strength (isometric)	Male football players (n = 28, 21.1±1.4)	Two PG randomized pre-post comparison. 1) Experimental (E, n = 13) Strengthening eccentric exercise program. Three days/week, 15min session. 2) Control (C, n = 11) only regular football training.	4 wk	Both groups: ↑ KFPTL (E g = 1.10 C g = 0.74) E:↑ OKEPTL (g = 0.87)
Clark *et al*. [30] 2005	Muscle strength (isokinetic)	Male Australian Rules football players (n = 9, >18 y)	Controlled within participants pre-post comparison. Progressive eccentric training involving only the Nordic Curl exercise (2 to 3 sets of 5 to 8 repetitions), 2–3 days/week	4 wk	↓QS at 60°/s⁻¹ (dominant g = -1.1; non-dominant g = -1); ↑OKFPTL (dominant g = 0.63; non-dominant g = 0.95)
Holcomb *et al*. [7] 2007	Muscle strength (isokinetic)	Female soccer players (n = 12; 20± 0.8 y)	Controlled within participants pre-post comparison. Upper-body resistance exercises combined with speed and agility (2 days) and lower body (hamstring emphasized) resistance exercises combined with endurance conditioning training (2 days). Four days/week.	6 wk	↑H/Q functional ratio (average from concentric 240, 180, and 60°/s⁻¹ and eccentric 60, 180, and 240°/s⁻¹; g = 1.19)
Daneshjoo *et al*. [31] 2012	Muscle strength (isokinetic)	Male, soccer players (n = 36, 17 to 20 y)	Three PG randomized pre-post comparison. 1) FIFA+11 (F, n = 12), involving strengthening, balance, plyometric and agility exercises 2) Harmoknee (H, n = 12) involving strengthening and balance exercises 3) control (C, n = 12) regular training and warm up. Both F and H consisted in 3 days/week (24 sessions), 20 to 25min workout.	8 wk	F: ↑H/Q conventional ratio (g = 0.99); and ↓H/Q (g = -1.17) functional ratio, from pre to post NS in H and C
Mendiguchia *et al*. [34] 2014	Muscle strength (isokinetic)	Males soccer players (n = 51)	Two PG randomized pre-post comparison **1)** Experimental (E, n = 27) Neuromuscular protocol involving eccentric hamstring muscle strength, plyometric, and accelerations 2) Control (C, n = 24) only football. Intervention consisted in 2 days/week (14 sessions), 30 to 35 min workout before the soccer session.	7 wk	↑HS (E, Con D g = 0.71, Non-D g = 0.69; ECC D g = 0.98, Non-D g = 0.70) ↑H/Q conventional ratio; (E, D g = 0.62, Non-D g = 0.60) and functional ratio (E, D g = 0.99, Non-D g = 0.48)

Table 3. (*Continued*)

Study	Assessment	Participants	Design and type of intervention	Length	Relevant findings
Mjølsnes *et al.* [35] 2004	Muscle strength (isometric and isokinetic)	Male soccer players (n = 22, >18 y)	Two PG randomized pre-post comparison. 1) Nordic eccentric hamstring (NEH, n = 11), 2) Concentric hamstring (CH, n = 10). Progressive training from 2 sets of 6 reps to 3 sets of 8 to 12 reps over 4 weeks, and then increasing load for the final 6 weeks	10 wk	NEH: ↑HS eccentric at 60°/s^{-1} (g = 2.16) ↑isometric at 30° (g = 1.86) 60° (g = 1.32) and 90° (g = 1.84) ↑H/Q functional ratio (g = 1.99) NS in CH

Notes: ↑ increase; ↓ decrease; PG: parallel groups; NS: no significant differences, Sig = significant differences. %EMG = percentage of electromyography activity; H = hamstring, MH = medial hamstring; Q = quadriceps; VM = vastus medialis; ST = semitendinosus; H/Q = hamstring to quadriceps ratio; QS = quadriceps strength, HS = hamstrings strength; PT = peak torque; DJ = Drop Jump; SLDJ = single legged drop jump; RVJ = Rebound vertical jump; VJ = Vertical Jump; HIFA = hip initial flexion angle; HPFA = hip peak flexion angle; HIAbdA = hip initial abduction angle; HPAbdA = hip peak abduction angle; HMxERA = hip maximum external rotation angle; HIerRA; HFM = hip flexion moment. KIFA = knee initial flexion angle; KPFA knee peak flexion angle; KVA; knee valgus angle KFM = knee flexion moment; KERM = knee external rotation moment; KPIRM = knee Peak internal-rotation moment; KPEM = knee peak extension moment; KPVM = knee peak valgus moment; OKFPTL = optimal knee flexion peak torque localisation OKEPTL = optimal knee extension peak torque localization.
* test 1 was performed between weeks 1 (pre) to 7 and test 2 (post) between week 18 to 25 during the 28-week intervention period.
** Missing information impeded the calculation of g values

Stop-jump

Four studies involving a total of 131 female athletes, investigated the effect of exercise programs on kinematic and kinetic variables during double leg stop-jump (DLSJ) [3,5,29,32]. The average quality score was 12, ranged from 9 to 14 (out of 16). The interventions lasted 4 to 9 weeks.

Two studies performed the DLSJ after basketball drills [3,32]. Participants dribbled a basketball to free throw line and then performed a jump shot. For the other two studies participants take a three or four steps approach to run as fast as they felt comfortable followed by two-footed landing and a maximum height two-footed takeoff [6,29].

Knee valgus angle was reduced as a result of a four-week progressive jump training program [3] or a mixed intervention involving strength and balance exercises assisted by a video feedback protocol [32]. Furthermore, Chappell and Limpisvasti [29] reported significant reduction of both knee valgus moment and hip flexion angle as consequence of a 6-week strength, balance, plyometric and agility program involving a constant monitoring of the proper technique execution. Only one of the aforementioned four studies did not report any significant modification in knee and hip biomechanics during a stop-jump after a 9-week strength training intervention using bands and balls in female athletes [6].

Muscle strength

Eleven trials involving 316 athletes (150 female and 166 male) reported the effects of exercise interventions on lower limb strength. Three studies considered only maximal isometric peak torques [6,36,38], seven studies measured isokinetic strength [7,11,28,30,31,33,34] and only one study measured both isometric peak torques and isokinetic force [35]. In addition, four of the aforementioned studies analyzed the effect of intervention on H/Q [28,30,31,34,35] and only two monitored changes on the optimal knee flexor peak torque localization [28,30]. The average quality score was 12.7, ranging from 10 to 15 (out of 16). The interventions lasted 4 to 10 weeks.

Both conventional and functional H/Q ratios increased after a 7-weeek neuromuscular multifaceted (plyometric, eccentric and acceleration exercises) program [34]. Additionally, functional H/Q ratio was also increased after a 4-week Nordic eccentric hamstring protocol in male

soccer players [35], and also following a 6-week strength program including at least two different hamstring concentric exercises in females soccer players [7]. However, the latest study did not result in significant modification of the conventional H/Q ratio. One study involving only male athletes examined the FIFA11+ and the HarmoKnee protocols. The FIFA11+ increased the conventional H/Q ratio only in the dominant leg but both protocols decreased the functional H/Q ratio [31]. Furthermore, no changes in the conventional H/Q ratio were observed after performing a 4-week eccentric exercise protocol involving different open or closed kinetic chain and antagonistic exercises [28]. Two studies reported a shift to the optimal knee flexor peak torque toward to a more open angle position following a 4-week eccentric exercise intervention [28,30].

Discussion

The main finding of the current review is that multifaceted programs including plyometric, balance, strength and/or agility exercises supported by appropriate feedback and technical indications seem to be more effective to positively modify biomechanical risk factors than protocols with no technical feedback, or involving only one mode of exercise. Furthermore, interventions using mainly strengthening exercises would improve muscle strength, H/Q ratios and/or promote a shift of optimal knee flexion peak torque toward a more open angle position, without further biomechanical modifications.

Landing

Kinetics and kinematics of the lower extremity during landing from vertical or rebound jumps, and from drop jump seem to be more modifiable compared to other testing maneuvers such as side-cutting or stop-jump. Multifaceted interventions involving strengthening, balance, flexibility, plyometric or agility exercises, supported by appropriate feedback and technical corrections showed to be effective to improve hip [29,33,39] and knee [3,11,29,33] biomechanics (Table 3). Conversely, when no feedback was used, less clear effects on knee kinetics during landing from single leg drop jump were observed [38]. Indeed, a non-desirable increase of knee initial flexion angle during landing from single legged drop jump was observed after performing a protocol including plyometric and balance exercises with no technical feedback [37]. The lack of feedback and/or proper technical support during an unstable 1-leg landing task could have been the reason of the observed results. Furthermore, the improvements on landing technique after performing a 4-week protocol involving resistance, flexibility and balance exercises supported by verbal and video feedback did not ameliorate when a subsequent 4-week plyometric and agility protocol was implemented [33]. Nonetheless, Herrington [3], observed a significant decrease of the knee valgus angle during landing from drop and stop-jump in female athletes after performing a 4-week progressive jump training program supported with proper verbal and technique feedback.

Results from the previous investigations support the importance of proper feedback and technical correction to successfully improve landing biomechanics when performing protocols including different exercise modalities.

Side-cutting

All of the included studies reported no effects of the injury prevention protocols to modify lower limb biomechanics during side-cutting maneuvers. Donnelly *et al.* [8] used a two parallel group design to compare the effectiveness of an intervention including balance, plyometric, agility exercises supported by feedback and technical corrections to a contrast shadow-training group. Although positive changes on the knee biomechanics during planned and unplanned

side cutting maneuvers were observed, both protocols were equally effective, and therefore no advantage of implementing the preventive intervention was determined. Possibly, the low supervisor-participants ratio (1:40) together with the lack of specific side-cutting exercises including in the preventive protocol would explain the achieved results. Additionally, Wilderman *et al.* [40] reported no effect of a 6-week progressive agility training to modify knee kinematics during a 45° side-step pivot maneuver. Perhaps the absence of specific exercises to address knee and hip flexion angles and the lack of feedback in regard to the knee and hip alignments would be the cause of the unsuccessful results. Moreover Zebis *et al.* [41] were also unable to observe positive modification on a side-cutting maneuver after performing an 18-week neuromuscular protocol in elite handball and soccer female players. Maybe the high level of performance of the participants would have impeded further biomechanical improvements on the selected side cutting exercises.

In summary, an effective protocol to improve lower limb biomechanics during side cutting maneuvers remains to be elucidated.

Stop-jump

Three studies using a 4-week [3,32] or a 6-week [29] multifaceted protocol including jumps and plyometric exercises combined with proper technical feedback improved knee valgus angle [3,32] and moment [29] during stop-jump. Conversely, a 9-week resistance-training program with no technical feedback, although effective to increase quadriceps and hamstring strength, did not produce any biomechanical modification during stop-jump [5]. The ineffectiveness of strength training alone to improve lower limb biomechanics during jump-related exercises was also observed in other studies [42,43]. Nevertheless, meaningful biomechanical improvements have been observed when strength protocols are combined with proper technical instructions and feedback [5].

The above-mentioned studies support the notion of combining sport-specific exercises with proper technical feedback to promote correct execution and biomechanical improvements during stop-jump. In addition, the positive effect of strength training maybe amplified by proper technical support to the sports-specific actions.

Muscle strength

Eleven studies investigated the effect of resistance exercises alone [6,28,30], combined with balance [36], agility, speed [7], flexibility, jump [33,38], plyometric and sprint training [34] or integrated within an standardized injury prevention protocol such as FIFA11+, Harmoknee [31] or Mandelbaum's Prevent Injury and Enhance Performance [11], Two interventions [30,35] using only the eccentric Nordic curl, improved hamstring strength along with a shift of the knee flexors maximal peak torque toward a more open angle position [30] and increase the functional H:Q ratio [35]. Further increases on the hamstring torque relationship were reported when this particular exercise was combined with an eccentric (single-leg dead lifts) and an unstable closed chain exercise (forward lunges on a Bosu® balance trainer).[36] Additionally, substantial improvements in the functional H/Q ratio were observed after a 7-week neuromuscular protocol involving two eccentric exercises (Nordic hamstring and dead lift), plyometric and sprints.[34] This multifaceted intervention induced twofold to threefold lower increases in quadriceps peak torque than in hamstring peak torque and consequently eliciting a meaningful increase of the functional H/Q ratio from 0.89 to 1.0.

A shift in maximal peak torque occurring at a more open knee angle position during both isokinetic flexion (+4°) and extension (+6.5°) was also observed as a results of a 4-week strengthening program where the Nordic curl was combined with three predominantly quadriceps

eccentric closed kinetic chain exercises.[28] Conversely, Holcomb *et al.* [7] reported meaningful increases of the H/Q ratios, especially at greater velocities, in a group of female soccer players after performing a 6-week of a multifaceted program including concentric but no eccentric hamstring exercises. As females have weaker hamstrings than men [44], it could be possible that in this particular group of female soccer players, no regular resistance training exercisers, a strengthening protocol with no particular eccentric hamstring components would be enough to initially improve hamstring activation and diminish disproportionate quadriceps force imbalance. Indeed similar results were observed by Herman [6] in female team sport athletes, with no regular resistance training, who increased hamstring and quadriceps isometric strength after a 9-week resistance bands and exercise balls protocol including no hamstring eccentric exercises.

Only Daneshjoo *et al.* [31] reported a non-desirable decrease of the H:Q functional ratio in both dominant and non-dominant limbs in male soccer players. This study analyzed the impact of two specific injury prevention programs (Harmoknee and FIFA11+) on conventional and functional H:Q ratio. Although no significant alterations were observed in the control and Harmoknee groups, participants allocated to the FIFA11+ showed a significant drop of the functional H:Q ratio from 0.83 to 0.49. The latest figures fall well below the recommended minimum threshold values of 0.89 on Biodex isokinetic dynamometer for preventing ACL injury in athletes [7]. Although both Harmoknee and FIFA11+ protocols include different types of strengthening, balance, running, plyometric and agility exercises, FIFA11+ involves greater knee extension components along with a relative lower emphasis on hamstring eccentric movements (only 1 set of 3 to 15 repetitions of Nordic curl) and therefore would be emphasizing quadriceps concentric over hamstring eccentric actions. Additionally, the interventions used in this particular study have taken place during the competition period with no preseason component. This sequence has shown to be detrimental to attenuate the incidence of ACL injury in female athletes [2]. Similarly Lephart *et al.* [33] reported a selective increase of quadriceps but not hamstring maximal peak torque in female team sport athletes after performing a multifaceted intervention excluding hamstring eccentric exercises. Conversely, Lim *et al.* [11] using another mixed protocol involving flexibility, plyometric, agility and strength exercises including 3 sets of 10 repetitions of Nordic curl, reported a reduction of quadriceps peak torque along with a positive increase of the hamstring activation during jumping in female basketball players. Although the influence of H/Q ratio as a risk factor for HAM injury has been questioned [45] lower values of both conventional and functional H/Q are still considered relevant risk factors for ACL injury [15]. Additionally, given the multifaceted etiology of both injuries the influence of H/Q ratios for increasing the risk of HAM and ACL injuries should not be ignored.

In summary, hamstring eccentric exercises such of Nordic curl, alone or integrated with other exercise modalities (unbalance, strengthening, plyometric, agility, sprint or flexibility) would improve hamstring strength and increase H/Q functional ratio along with or a shift of optimal knee flexion peak torque toward a more open angle position. Nevertheless, less strength-conditioned athletes would initially benefit from using multifaceted protocols including concentric hamstring, balance and other resistance exercises. Furthermore, in team sport involving a predominance of knee extension actions such as soccer or basketball it would be recommended to add hamstring eccentric exercises in order to balance the predominance of knee extension component resulted from the specific sport activities (e.g. jump-landing, stop-jump or side cutting maneuvers).

Limitations and future studies

Seven studies were non-randomized single trials interventions [3,7,29,30,37,39,41], while one study [8] used a two parallel group non-randomized comparison. The lack of a parallel control

group and randomization creates potential discordance among groups and introduces inherent selection bias that is difficult to ignore.

All the included studies focused on very specific and relatively homogeneous populations, e.g. male Australian Rules football players [30] male professional [28] or amateur [36] soccer players; female national league division I basketball players [3], etc. Maybe the specific training methods, including volume and intensity of different conditioning training, sport drills and competitive actions, body type, genetic variability, and other confounders would make it difficult to generalize results worldwide.

The uncertain effects of the analyzed risk factors to attenuate the incidence of both HAM and ACL injuries impede to make real assertions about the benefits of the used protocols to reduce the injury rate, rather than to elicit supposed beneficial alterations in some of the analyzed biomechanical and neuromuscular variables. In addition, from the analyzed studies, it was not possible to evaluate the duration of the effects and what would be the effective training dosage to maintain the obtained benefit over the complete season and between seasons. Futures studies using longer intervention periods lasting from more than 1 season should be designed in order to clarify proper dosage for maintaining and/or recover benefits on the analyzed modifiable injury risk factors in team sports athletes.

Conclusions

Multifaceted programs including eccentric hamstring exercises combined with other training modalities such as plyometric, balance, resistance, agility and/or flexibility exercises would promote positive modifications on the previously identified HAM and ACL risk factors. The addition of appropriate technical feedback appears to be an essential component of the injury prevention protocols in team sport athletes.

Supporting Information

S1 Table. PRISMA Checklist.
(DOC)

S2 Table. Supporting information including the 56 excluded studies and reasons for exclusion.
(DOCX)

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Effectiveness of Knee Injury and Anterior Cruciate Ligament Tear Prevention Programs: A Meta-Analysis

Abstract

Objective

Individuals frequently involved in jumping, pivoting or cutting are at increased risk of knee injury, including anterior cruciate ligament (ACL) tears. We sought to use meta-analytic techniques to establish whether neuromuscular and proprioceptive training is efficacious in preventing knee and ACL injury and to identify factors related to greater efficacy of such programs.

Methods

We performed a systematic literature search of studies published in English between 1996 and 2014. Intervention efficacy was ascertained from incidence rate ratios (IRRs) weighted by their precision (1/variance) using a random effects model. Separate analyses were performed for knee and ACL injury. We examined whether year of publication, study quality, or specific components of the intervention were associated with efficacy of the intervention in a meta-regression analysis.

Results

Twenty-four studies met the inclusion criteria and were used in the meta-analysis. The mean study sample was 1,093 subjects. Twenty studies reported data on knee injury in general terms and 16 on ACL injury. Maximum Jadad score was 3 (on a 0–5 scale). The summary incidence rate ratio was estimated at 0.731 (95% CI: 0.614, 0.871) for knee injury and 0.493 (95% CI: 0.285, 0.854) for ACL injury, indicating a protective effect of intervention. Meta-regression analysis did not identify specific intervention components associated with greater efficacy but established that later year of publication was associated with more conservative estimates of intervention efficacy.

Conclusion

The current meta-analysis provides evidence that neuromuscular and proprioceptive training reduces knee injury in general and ACL injury in particular. Later publication date was associated with higher quality studies and more conservative efficacy estimates. As study quality was generally low, these data suggest that higher quality studies should be implemented to confirm the preventive efficacy of such programs.

Introduction

Approximately seven million high school students participate in team sports each year [1] with 3–11% advancing to compete in NCAA college athletics [2]. Injuries occur frequently among these young athletes, with knee injuries accounting for 10–25% of all sports-related injuries [3]. Athletes involved in jumping, pivoting, or cutting, such as skiers or soccer players, are at increased risk for serious knee injuries including anterior cruciate ligament (ACL) tears. An estimated 250,000 ACL-related injuries occur annually in the United States [4], leading to 80,000 to 100,000 surgical ACL reconstruction surgeries per year [5]. Additionally, female athletes are 2 to 8 times more likely to injure their ACL compared to their male counterparts [6–8]. Serious knee injury may result in instability, damage to menisci or cartilage, reconstructive surgery and early osteoarthritis [9–11].

A growing number of prevention programs have been designed to reduce the incidence of knee injury in athletes, with many targeting ACL injuries specifically. These programs emphasize neuromuscular and proprioceptive training to reduce landing forces and adduction and abduction moments [12, 13]. Incorporated into these interventions are stretching, strengthening, and balance exercises as well as exercises that promote awareness of high-risk positions, enhance sports-specific agility, and improve technique. In four previously reported meta-analyses, injury prevention training programs significantly reduced knee and ACL injuries among young athletes [13–16]. However, these meta-analyses were limited by the number of studies they included and by the statistical methods utilized [13–16]. Our study adds substantially to the literature by almost doubling the numbers of ACL-specific studies included, by analyzing both knee and ACL injuries and by applying robust statistical methods. Our approach led to a more robust estimate of the association between injury prevention and neuromuscular/ proprioceptive intervention.

Methods

This study was conducted according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol [17].

Search Method

We performed a systematic literature search in the PubMed, MEDLINE/ EMBASE, CINAHL, Cochrane Central Register of Controlled Trials, and Web of Science databases through December 23, 2014. Our literature search was performed using the following search terms: [knee injury OR knee injuries OR anterior cruciate ligament injury OR anterior cruciate ligament injuries OR ACL injury OR ACL injuries OR lower limb injury OR lower limb injuries] AND [prevention]. We limited each search to peer-reviewed manuscripts published in English.

Inclusion and Exclusion Criteria

Duplicate titles and studies published prior to 1996 were excluded following the literature search. Only literature published between 1996 and 2014 were included in order to capture the most recent trends in neuromuscular/proprioceptive prevention programs. Two reviewers (KK and MGG) independently screened unique studies based on the title and abstract and excluded studies that did not meet the selection criteria. Studies were considered for inclusion if the intervention used neuromuscular or proprioceptive training to prevent knee or ACL injuries in human subjects, and if the study outcomes included knee or ACL injury incidence. Review papers, editorials, lectures, commentaries, abstracts, trial design papers, case studies, surgical techniques, articles that were not peer-reviewed, and theses were excluded. Following the title/abstract screen, MGG and KK independently reviewed the full text of those articles selected for inclusion to confirm that the studies met all inclusion criteria. When the two reviewers did not agree, a third reviewer (HYY) was consulted to reach a consensus. Following full paper review, KK and MGG examined the references of included studies to identify other relevant papers for analysis.

Data Abstraction

Two reviewers (KK and MGG) independently abstracted the following data from all articles meeting inclusion criteria: first author, year of publication, title, sport type, subject sex, subject age, country in which the study was conducted, number of subjects in the control and intervention groups, intervention characteristics/components, and knee and/or ACL injury outcome data. Reviewers scored each study based on the Jadad scale in order to measure the quality of included papers [18]. Abstracted data were compared, and discrepancies were adjudicated by a third author (HYY).

Analysis

We used the incidence rate ratio (IRR) as the effect measure estimate, as it takes into consideration the variability in exposure time (exercise and play) among teams. The IRRs were obtained from each study or calculated from the number of injuries and exposure time if not provided. IRRs were combined into a weighted average, weighted by the precision of each IRR estimate (1/variance). In the case of clustered designs, variance estimates were conservatively adjusted for within team correlation [19].

We made a number of assumptions in our study. For trials that used a cluster design, when the intraclass correlation coefficient (ICC) was not reported, we assumed an ICC of 0.035 (mean ICC among those studies reporting ICC) to account for clustering outcomes within cluster groups, such as teams and coaches. Sensitivity analyses were conducted to test this assumption. Three studies did not report knee- or ACL-specific ICCs but reported ICCs for overall injuries or other lower limb injuries [11, 20, 21]. For these studies, we used reported ICCs as proxies for knee and ACL ICCs. Additionally, some studies performed interventions in multiple seasons [22, 23]. For these studies, we selected data from the first season to reduce the occurrence of repeat players and estimation bias (depletion of players more susceptible to injury) arising from one season to the next. A few studies did not report exposure (play and exercise) time [21, 24–27]. For these studies we assumed equal exposure time across treatment and control groups. Jadad scores were calculated to assess the methodological quality of each study (range 0 to 5; 5 indicating a rigorous study) [18].

We assessed publication bias graphically using funnel plots, and then assessed the between-study heterogeneity, first using funnel plots, and then with quantitative measures of heterogeneity, including statistical influence, inconsistency, and other measures (H, I^2 and Q-term). Per

convention, negative values of I^2 were set to zero [28]. These measures were factored into decisions to retain or exclude specific studies from the analysis [29]. Studies with a strong influence on heterogeneity were excluded from our main analysis, though we included all studies in a sensitivity analysis. Meta-analysis summary estimates were based on the study IRRs weighted by their precision using a random effects model. We used forest plots summarizing the natural log of the IRR across studies to depict results of the meta-analysis graphically. The vertical line at ln IRR = 0 provides a reference for a null result. We used the ln IRR so that the confidence intervals are symmetrical about the means and to accurately display IRRs that are less than one.

We used meta-regression to determine the effect of various training strategies and study characteristics, including the year of publication, on the incidence rate ratio [30]. We examined the following technical components: balance training, plyometric (jump) training, strength/resistance training, running technique training (combined technique training and running exercises (e.g. shuttle run, bounding run, etc.)), and stretching. We created a composite score to evaluate whether programs with more components had better or worse outcomes by summing the number of technical components (possible range: 0 to 5). We also examined age of the cohort (high school or younger vs. older than high school) and whether the intervention included pre-season training. Finally, we conducted a subgroup analysis restricted to studies that reported non-contact injuries in order to identify the efficacy of intervention on non-contact ACL injuries.

Results

Studies Included in the Analysis

The initial search algorithm returned 5,946 titles. Fig 1 presents the literature review search results. Twenty-four studies met our inclusion criteria and were therefore analyzed to evaluate the effect of neuromuscular or proprioceptive training on knee and ACL injury prevention. Of the 24 studies, 1 took place in Australia [21], 1 in Canada [31], 7 in the United States [22, 24, 32–36], and the remaining 15 took place in Europe (Denmark [37], Finland [20], Switzerland [38], Germany [26], Greece [27], Italy [25, 39], Netherlands [40], Norway [11, 23, 41, 42], or Sweden [43–45]). Fourteen of the interventions were carried out on soccer players, 4 on handball players, 1 on floorball players, 1 on basketball players and 1 on Australian Army recruits. Three studies intervened on multiple sports (2 studies focused on soccer, basketball and volleyball, and 1 study focused on soccer and basketball). The mean study sample was 1,093 subjects (standard deviation [SD] 1,077). Fifteen of the studies focused on women only; four focused on men only; three included men and women, and two studies did not report the sex of study subjects. Five studies used a Federation International de Football Association (FIFA) training program [36, 38–40, 42], 3 studies used a Prevent Injury and Enhance Performance (PEP) or modified PEP program [22, 34, 41], 1 study used the Frappier Acceleration Training Program [24], 1 study used the HarmoKnee Preventive Training Program [44], 1 study used the plyometric-based knee ligament injury prevention (KLIP) program [33], and 13 studies used proprietary programs. Sixteen studies reported data on ACL injury; however, in 2 of these studies, one or both groups experienced zero ACL injuries [36, 44]. As a result, the IRR could not be calculated for these studies, and they were not included in the ACL meta-analysis. A sensitivity analysis was conducted to include these studies after assigning a value of 0.5 to zero injury counts. Twenty studies reported data on knee injury, seventeen of which included all knee injury types and three of which [20, 27, 32] defined knee injuries specifically as knee ligament injuries. Seven studies reported both contact and non-contact injuries [20, 23, 26, 32, 34, 44,
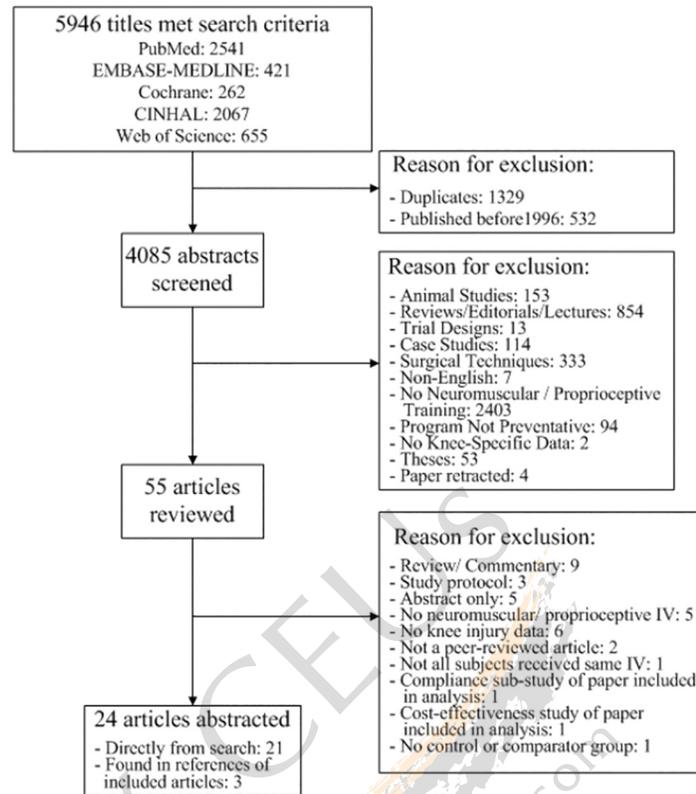
Fig 1. PRISMA Flow Diagram.

45], while 4 studies reported non-contact injuries only [21, 22, 33, 35]. Thirteen studies did not specify whether knee/ ACL injuries were contact or non-contact.

Knee Injury Prevention

Twenty (of 24) studies evaluated prevention of knee injury [11, 20, 21, 24, 26, 27, 31, 32, 34–45]. The second to last column of Table 1 lists the IRR and 95% confidence intervals for each of these studies. Fig 2 displays funnel plots of precision (weight) by natural log of the IRR. The plot for knee injury has two peaks (Fig 2A), indicating potential heterogeneity. The plot also shows some skewness with more studies falling toward the left tail (indicating superiority of the intervention). Quantitative measures indicate moderate inconsistency and heterogeneity ($I^2 = 0.294$, H = 1.190 respectively). The estimates from Heidt et al (depicted on the plot) contributed the most substantial weight to the heterogeneity score (Q-term = 9.965) and had high influence (Influence = 0.215). After eliminating Heidt et al from the analysis, the 19 remaining studies were depicted by a funnel plot with a single peak (Fig 2B). The plot shows symmetry around the peak, failing to suggest publication bias. Quantitative measures indicate low heterogeneity ($I^2 = 0$, H = 0.964 respectively), which support combining individual studies (excluding Heidt et al) into a single summary estimate.

The meta-analysis random-effect IRR (excluding Heidt et al) was 0.731 (95% CI: 0.614, 0.871), indicating that neuromuscular/ proprioceptive interventions significantly reduced knee injury by 26.9%. The results of the meta-analysis for knee injury prevention are presented graphically in a forest plot (Fig 3A).

Table 1. Study specific incident rate ratio (95% confidence interval) for the impact of neuromuscular training programs to reduce knee or anterior cruciate ligament (ACL) injury.

	First Author (Date)	Study Design	Sample Size	Sport	Jadad Score	Sex	Age (High School-aged vs. Older than High School)	Program Components[1]	Incidence Rate Ratio (95% Confidence Interval)	
									Knee Injury	ACL Injury
1	Goodall[21] (2013)	Cluster randomized trial	779	Military Training	3	Female, Male	Older than High School	P, B, R/T	0.796 (0.523, 1.212) †	
2	Grooms[36] (2013)	Prospective cohort study	64	Soccer	1	Male	Older than High School	P, B, S/R, R/T, S	0.895 (0.056, 14.303) ‡	
3	vanBeijsterveldt [40] (2012)	Cluster randomized trial	456	Soccer	1	Male	Older than High School	P, B, S/R, R/T, S	0.627 (0.327, 1.203) ‡	
4	Walden[45] (2012)	Cluster randomized trial	4,564	Soccer	3	Female	High School-aged	P, B, S/R, R/T	0.902 (0.604, 1.346)	0.433 (0.175, 1.072)
5	Longo[39] (2012)	Cluster randomized trial	121	Basketball	1	Male	High School-aged	P, B, S/R, R/T, S	1.338 (0.199, 8.991) ‡	
6	LaBella[35] (2011)	Cluster randomized trial	1,492	Soccer Basketball	3	Female	High School-aged	P, S/R, R/T	0.446 (0.130, 1.537) ‡	0.164 (0.025, 1.080) ‡
7	Emery[31] (2010)	Cluster randomized trial	744	Soccer	1	Female, Male	High School-aged	P, B, S/R, R/T, S	0.368 (0.070, 1.940)	
8	Kiani[44] (2010)	Prospective cohort study	1,506	Soccer	0	Female	High School-aged	P, B, S/R, R/T	0.229 (0.049, 1.071) ‡	
9	Soligard[41] (2008)	Cluster randomized trial	1,892	Soccer	1	Female	High School-aged	P, B, S/R, R/T, S	0.549 (0.326, 0.925)	
10	Gilchrist[34] (2008)	Cluster randomized trial	1,435	Soccer	1	Female	Older than High School	P, S/R, R/T, S	1.036 (0.605, 1.776) ‡	0.584 (0.182, 1.878) ‡
11	Pasanen[20] (2008)	Cluster randomized trial	457	Floorball	3	Female	Older than High School	P, B, S/R, S, R/T	0.493 (0.186, 1.307)	1.161 (0.315, 4.274)
12	Steffen[42] (2008)	Cluster randomized trial	2,020	Soccer	3	Female	High School-aged	P, B, S/R, R/T, S	1.220 (0.612, 2.433)	0.792 (0.120, 5.205)
13	Pfeiffer[33] (2006)	Prospective cohort study	1,439	Soccer, Basketball, Volleyball	0	Female	High School-aged	P, R/T		2.153 (0.321, 14.447) ‡
14	Mandelbaum[22] (2005)	Prospective cohort study	2,946*	Soccer	0	Female	High School-aged	P, S/R, R/T, S		0.114 (0.018, 0.723) ‡
15	Petersen[26] (2005)	Prospective matched cohort	276	Handball	1	Female	Older than High School	P, B, R/T	0.474 (0.127, 1.765)†‡	0.190 (0.014, 2.523) †‡
16	Olsen[11] (2005)	Cluster randomized trial	1,837	Handball	2	Female, Male	High School-aged	P, B, S/R, R/T	0.530 (0.264, 1.064)	0.280 (0.045, 1.747)

Table 1. (*Continued*)

	First Author (Date)	Study Design	Sample Size	Sport	Jadad Score	Sex	Age (High School-aged vs. Older than High School)	Program Components[1]	Incidence Rate Ratio (95% Confidence Interval)	
									Knee Injury	ACL Injury
17	Malliou[27] (2004)	Prospective cohort study	100	Soccer	0	Not Reported	High School-aged	B	0.500 (0.209, 1.194) †‡	
18	Myklebust[23] (2003)	Prospective cross-over study	1,797*	Handball	0	Female	Older than High School	P, B, R/T		0.960 (0.491, 1.875) ‡
19	Junge[38] (2002)	Prospective cohort study	194	Soccer	1	Male	High School-aged	P, B, S/R, R/T, S	0.697 (0.283, 1.721) ‡	
20	Heidt[24] (2000)	Randomized trial	300	Soccer	1	Female	High School-aged	P, S/R, R/T	0.103 (0.032, 0.340)† ‡	0.125 (0.016, 0.999)† ‡
21	Soderman[43] (2000)	Cluster randomized trial	140	Soccer	2	Female	Older than High School	B	1.831 (0.537, 6.240) ‡	5.492 (0.434, 69.533)‡
22	Hewett[32] (1999)	Prospective cohort study	829	Soccer, Volleyball, Basketball	0	Female	High School-aged	P, S/R, R/T, S	0.269 (0.033, 2.217) ‡	0.537 (0.055, 5.251) ‡
23	Wedderkop[37] (1999)	Cluster randomized trial	237	Handball	1	Female	High School-aged	P, B, S/R	0.301 (0.050, 1.812) ‡	
24	Caraffa[25] (1996)	Prospective cohort study	600	Soccer	0	Not Reported	Older than High School	B		0.143 (0.064, 0.321) †‡

[1] P: plyometric (jump training); B: balance exercises; S/R: strength/ resistance training; R/T: running/ technique training exercises (e.g. shuttle run, bounding run, etc.); S: stretching

[2] Average age reported for injured players only

† No estimate of exposure time.

IRR estimates were calculated assuming equal exposure time across groups.

‡ No correlation coefficient or inflation factor reported.

Confidence intervals were calculated assuming a correlation coefficient of 0.035

* Only control season and first intervention season included

ACL Injury Prevention

Sixteen studies evaluated prevention of ACL injury [11, 20, 22–26, 32–35, 42, 43, 45]. The last column of Table 1 lists the IRR and 95% confidence intervals for impact of the program on ACL injury prevention. A funnel plot of the 14 ACL studies analyzed (Fig 4A) is relatively symmetric, but depicts two peaks, indicating potential heterogeneity. Quantitative measures of heterogeneity also estimated moderate inconsistency and heterogeneity ($I^2 = 0.516$, H = 1.438 respectively). The estimates from Myklebust et al [23] and Caraffa et al [25] (depicted on the plot) were the most influential (Influence = 1.547, 1.848 respectively). These studies also contributed substantial weight to the heterogeneity score (Q-term = 4.322, 8.374 respectively). Soderman et al [43] had high heterogeneity score (Q-term = 3.59), but was not influential
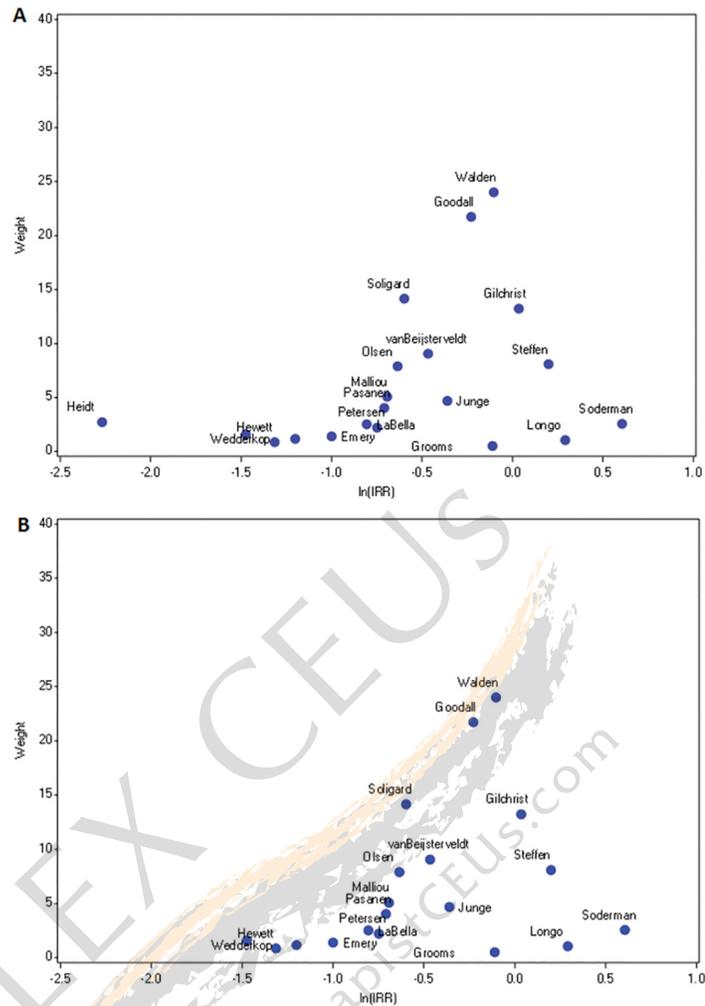
Fig 2. Sensitivity Analyses: Funnel plots of weight by natural log of the incidence rate ratio for knee injury. Panel A includes all 20 studies of knee injury, while Panel B includes only 19 studies of knee injury (excluding Heidt et al).

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(Influence = 0.067). Therefore we decided to retain the study by Soderman et al in our analysis. After eliminating studies by Caraffa et al and Myklebust et al, the 12 remaining studies displayed a more balanced distribution in the funnel plot with a single peak (Fig 4B). Further, quantitative measures of heterogeneity dropped well below moderate levels ($I^2 = 0.221$; $H = 1.133$).

The meta-analysis random-effect IRR (excluding Caraffa et al and Myklebust et al) was 0.493 (95% CI: 0.285, 0.854), indicating that neuromuscular/proprioceptive interventions significantly reduced ACL injury by 50.7%. The results of the meta-analysis for ACL injury prevention are presented graphically in a forest plot in Fig 3B. These results do not include two studies that reported zero ACL injuries in one or both groups [36, 44].

Meta-Regression

Among knee injury studies, none of the specific training components were statistically significantly associated with outcome in meta-regression (Table 2). Two studies included 1 of 5
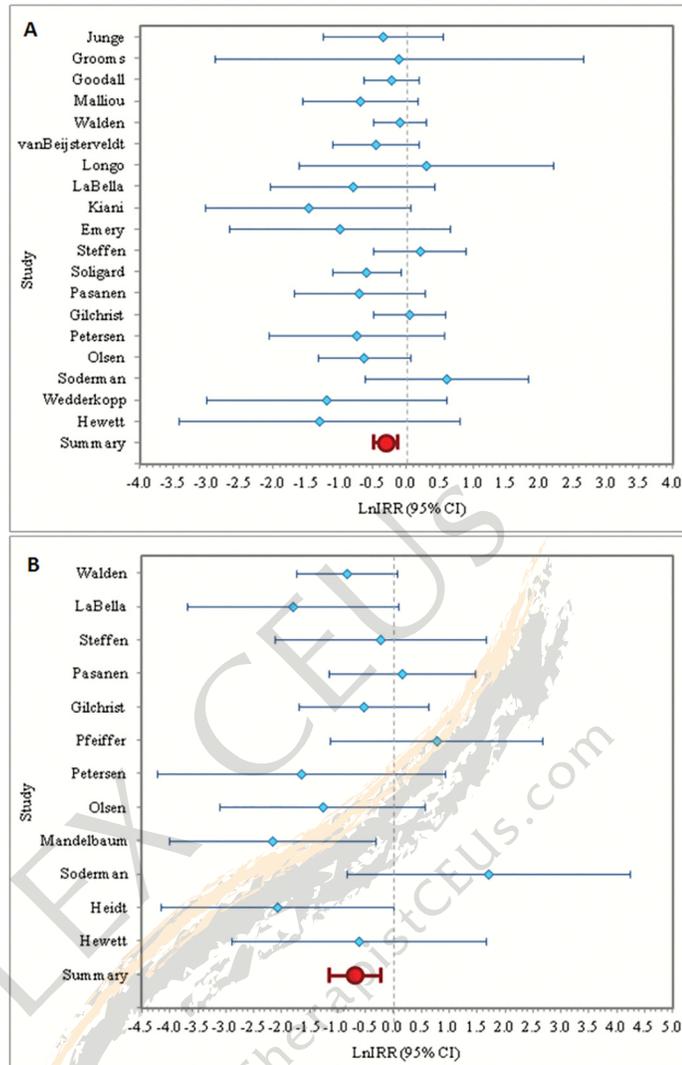
Fig 3. Forest plots of the natural log of IRR and 95% confidence interval for knee and ACL injuries excluding studies that contribute to heterogeneity. Summary estimates from the meta-analysis are presented at the bottom of the plot in red. A) Forest plot of the natural log of IRR and 95% confidence interval for knee injury excluding Heidt et al. B) Forest plot of the ln IRR and 95% confidence interval for ACL injury excluding Caraffa et al and Myklebust et al.

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training components (Malliou and Soderman, balance training only), 5 studies included 3 components, 5 studies included 4 components, and 8 studies included all 5 technical components. We did not find an association between number of components and outcome when evaluating the technical components (p = 0.5448), and there were no obvious trends (e.g., more components being associated with better outcomes or vice versa). We also did not find a statistically significant association between training components and outcome among ACL injury studies. Again, none of the composite measures were significantly associated with outcome.

Age, classified as high school aged or younger versus older than high school aged, was not significantly associated with outcome for either knee or ACL injuries. Having training as part of the pre-season (pre-season only or pre-season and in-season) versus in-season only was
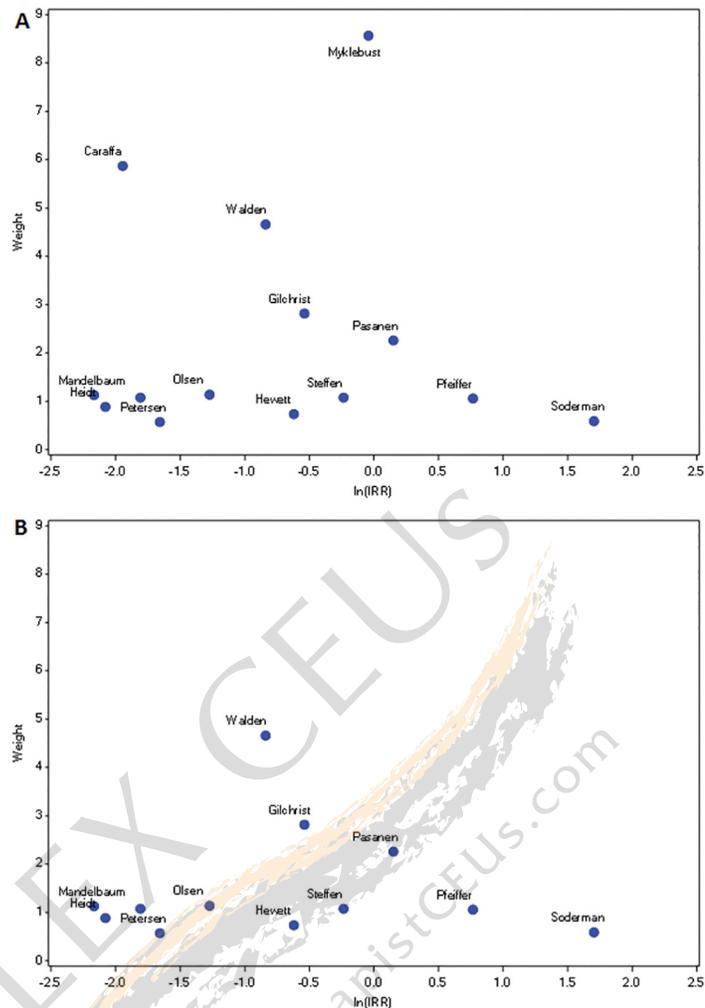
Fig 4. Sensitivity Analyses: Funnel plots of weight by natural log of the incidence rate ratio for ACL injury. Panel A includes all 14 studies of ACL injury, while Panel B includes only 12 ACL studies (excluding Caraffa et al and Myklebust et al).

associated with a lower risk of knee injury (p = 0.0016). The trend for a lower risk of injury was also evident for ACL injuries, though this did not reach statistical significance (p = 0.3281).

Later year of publication was associated with more conservative estimates of intervention efficacy. For knee injury the p-value for the trend was 0.0544. For ACL injury the association had less certainty (p = 0.3417) (Fig 5). Higher Jadad scores were associated with more conservative estimates of intervention efficacy. The trend reached statistical significance for knee injury (0.0289) and did not for ACL injury (0.5913).

Subgroup Analysis

We performed a subgroup analysis to assess the effectiveness of prevention intervention on non-contact injuries. Nine studies reported non-contact ACL injuries [20, 22, 23, 26, 32–35, 45]. Two studies were excluded because they reported injury counts of zero [36, 44]. The meta-analysis random-effect IRR for the 7 remaining studies was 0.513 (95% CI: 0.298, 0.884).

Table 2. Results of Meta-Regression.

Component	Knee Injury			ACL Injury		
	n (%)	IRR	P-value*	n (%)	IRR	P-value*
Balance training			0.3677			0.5142
No	4 (20%)	0.503		6 (43%)	0.359	
Yes	16 (80%)	0.681		8 (57%)	0.530	
Plyometric (jump) training			0.5907			0.5182
No	2 (10%)	0.810		2 (14%)	0.497	
Yes	18 (90%)	0.639		12 (86%)	0.311	
Strength/ resistance Training			0.5268			0.4567
No	4 (20%)	0.751		5 (36%)	0.389	
Yes	16 (80%)	0.624		9 (64%)	0.608	
Running Technique training			0.8871			0.5182
No	3 (15%)	0.690		2 (14%)	0.497	
Yes	17 (85%)	0.652		12 (86%)	0.311	
Stretching			0.4007			0.6638
No	10 (50%)	0.587		9 (64%)	0.547	
Yes	10 (50%)	0.723		5 (36%)	0.421	
Age			0.1995			0.4097
High School	13 (65%)	0.791		8 (57%)	0.363	
> High School	7 (35%)	0.579		6 (43%)	0.581	
Intervention Period			0.0016			0.3281
Pre-Season	5 (25%)	0.237		5 (36%)	0.323	
During Season only	15 (75%)	0.754		9 (64%)	0.573	

* The p-value tests a difference in IRR between categories.

Sensitivity Analyses

Knee Injury.   We assessed the effectiveness of intervention including studies with strong influence of heterogeneity. Results are presented graphically in a forest plot (Fig 6A). Inclusion of Heidt et al in the analysis of knee injury prevention changed the random-effect IRR of knee injury from 0.731 to 0.658 (95% CI: 0.523, 0.827). This result was consistent and indicated a significant reduction of risk of knee injury in neuromuscular/ proprioceptive intervention groups. Next, we evaluated the study assumption that ICC = 0.035 for studies where ICC was not reported. The maximum of reported ICC was 0.071. We tested a range of intraclass correlation coefficients between 0.000 and 0.080 and found that varying intraclass correlation coefficients did not affect the results.

ACL Injury.   Inclusion of Caraffa et al and Myklebust et al in the analysis of ACL injury prevention resulted in a random-effect IRR of ACL injury of 0.460 (95% CI: 0.264, 0.804), close to the main analysis IRR of 0.493. These results are presented graphically in a forest plot (Fig 6B). Additionally, two studies (Kiana et al and Grooms et al) reported zero ACL injuries in one or both groups. We conducted a sensitivity analysis including these two studies with a 0.5 correction for zero injury counts. The results remained consistent (random-effect IRR = 0.466 [95% CI: 0.331, 0.656]). As with the knee injury analysis, we evaluated the study assumption that ICC = 0.035 for studies where ICC was not reported and found that varying the ICC did not affect the results.
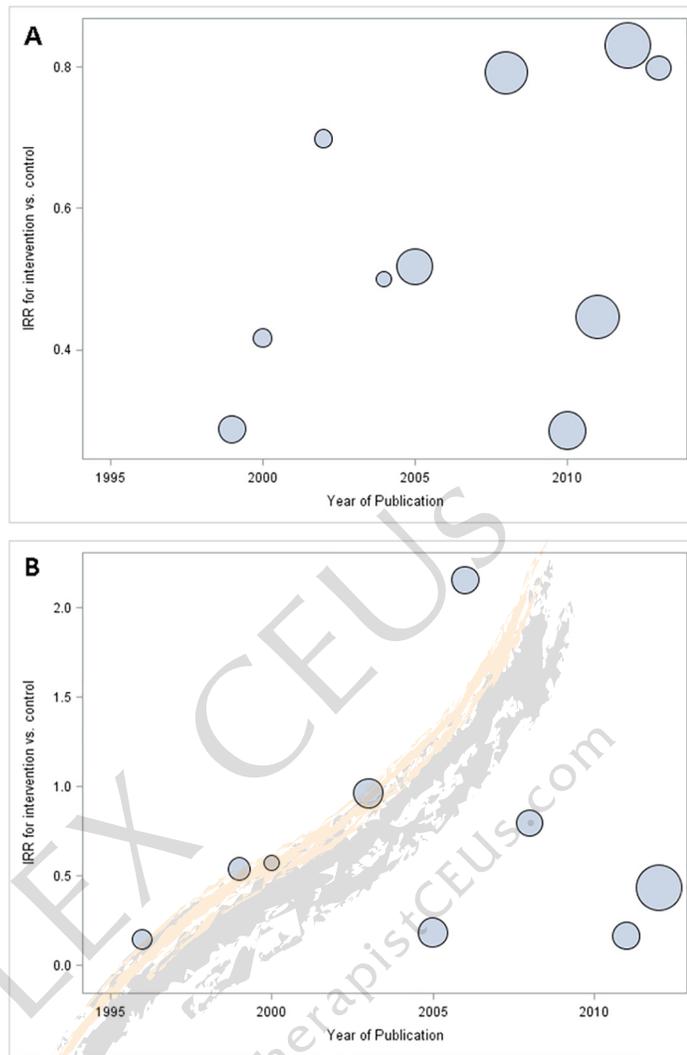
Fig 5. Meta-Regression: Year of Publication. This figure shows the association between the year of publication and intervention efficacy for A) knee injury and B) ACL injury. Publication year is along the X-axis, and each dot represents the summary IRR for that year. The size of the bubble corresponds to the average sample size for studies published in that year.

Discussion

In the current study, we aimed to summarize the effects of neuromuscular and proprioceptive training on knee and ACL injury reduction. We conducted a meta-analysis of 24 controlled trials of preventive interventions for knee and ACL injuries. Using an overall IRR estimate as the summary estimate of effect, both the studies of knee injury and the studies of ACL injury demonstrated statistically significant reductions in injury rates associated with preventive interventions. We found that neuromuscular and proprioceptive prevention programs appeared to reduce knee injuries by 26.9% and ACL injuries by 50.7%.

Among the 20 studies reporting knee injury rates, four [32, 35, 40, 44] reported a statistically significant association between the intervention and knee injury prevention in their original manuscripts. Twelve studies reported a reduction in knee injuries that did not reach statistical
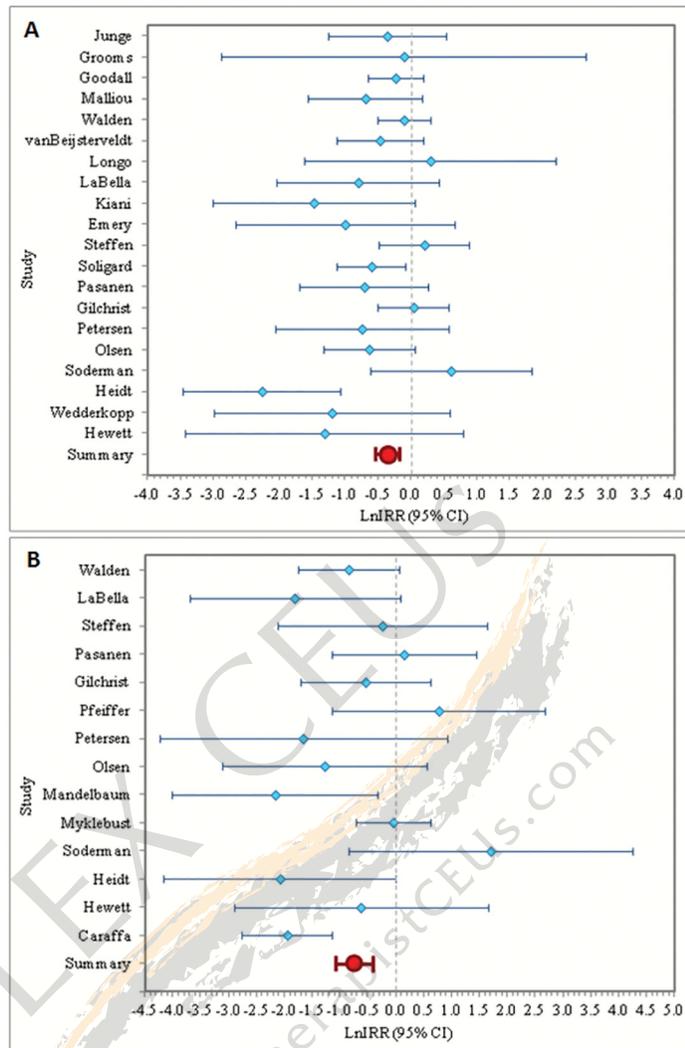
Fig 6. Sensitivity Analyses. Forest plots of the ln IRR and 95% confidence interval, including studies that contribute to heterogeneity. Panel A shows the forest plot for knee injury, including Heidt. Panel B shows the forest plot for ACL injury, including Caraffa and Myklebust. Summary estimates from the meta-analysis are presented at the bottom of the plot in red.

significance. Nine studies reported a significant reduction in total injuries examined [11, 20, 24, 27, 36–39, 41]. Our primary meta-analysis of IRR estimates supported the protective effect of neuromuscular and proprioceptive training on knee injury reduction.

Among the 14 studies reporting ACL injury rates, 4 reported a statistically significant association between the intervention and injury prevention in their original manuscripts [22, 25, 32, 45]. Seven studies reported a reduction in knee injuries that did not reach statistical significance. Our primary meta-analysis of IRR estimates supported this protective finding.

Our findings build upon several previous meta-analyses evaluating ACL prevention methods conducted by Hewett et al, Yoo et al, Grimm et al and Sadoghi et al [13–16]. All analyses conducted by Hewett et al (2006), Yoo et al (2010) and Sadoghi el al (2012) found a significant protective effect of prevention programs on ACL injuries. The magnitude of the effect was

similar for the three studies: Hewett et al included 6 studies and found an odds ratio of 0.40 (95% CI: 0.26, 0.61); Yoo et al analyzed seven studies (including all 6 of those in Hewett et al) and found an odds ratio of 0.40 (95% CI: 0.27, 0.60); Sadoghi et al included 8 studies (5 included by Hewett et al or Yoo et al) and found a risk ratio of 0.38 (95% CI: 0.20, 0.72). All three analyses were limited to females only and did not assess the effect of prevention programs on the more general grouping of knee injuries. In 2014, Grimm et al conducted a meta-analysis to assess the protective effects of knee injury prevention programs on knee and ACL injury incidence among male and female athletes. They limited their study to Level I randomized controlled trials of soccer players. Their analysis included nine studies, seven of which were not included in any of the previous meta-analyses [43]. They observed a statistically significant reduction in the risk of knee injury, with a summary risk ratio of 0.74 (95% CI: 0.55, 0.98). The prevention programs showed a protective effect for ACL injury, but this did not reach statistical significance, with a summary risk ratio of 0.66 (95% CI: [0.33, 1.32], p = 0.238).

Results of analyses examining specific training components have been mixed. Sadoghi et al did not find a statistically significant association between balance board use or use of video assistance and injury prevention [14], while Yoo et al found a protective but non-significant effect of plyometric and strengthening components in subgroup analysis [15]. In our analysis, we did not find a significant association between any single training component and injury prevention, neither for ACL injury nor for knee injury. We did find that interventions started in the pre-season (IRR 0.237), rather than during the season (IRR 0.754), were better at preventing knee injuries (p = 0.0016) and had a protective but non-significant effect for ACL injuries. Sadoghi et al also found a protective, non-significant, effect of pre-season interventions for ACL injuries [14]. These results suggest that it may not be the individual program components that are important, but the timing of the intervention.

Since Sadoghi's meta-analysis, four additional ACL studies have been published [35, 36, 44, 45], only one of which [45] was included in Grimm et al. We have also added five older studies that met our inclusion criteria [11, 20, 23, 42, 43], only two of which [42, 43] were used in Grimm et al. In our analysis the IRR estimate was selected as the measure of effect rather than the odds ratio or risk ratio, as the IRR adjusts for exposure time. Variances were conservatively adjusted for within team correlation in clustered designs, and sensitivity analyses were conducted to test the assumptions of design effects. These methods were not employed by Hewett et al, Sadoghi et al, Yoo et al, or Grimm et al, although these meta-analyses included studies with clustered designs. Additionally, we addressed the limitations in the assessment of heterogeneity in previous meta-analyses [13, 16]. We assessed heterogeneity both graphically and quantitatively. Based on our assessment, we identified and excluded studies that contributed substantially to heterogeneity and selected the most appropriate meta-analytic modeling methods. We used multiple sensitivity analyses to confirm our primary findings.

The results of the meta-analysis reported in this paper should be viewed within the limitations of the included studies. The majority of the studies (63%) included in our analysis focused on injury prevention exclusively in female athletes; therefore, our results should be generalized cautiously to male athletes. Thirteen [11, 24, 25, 27, 31, 36–43] of the included studies did not distinguish between contact and noncontact knee or ACL injuries; therefore, in our main analysis, we analyzed all ACL injuries (contact and noncontact) when both were reported. In a subgroup analysis, we examined non-contact ACL injuries exclusively and found comparable results but were limited in the number of studies that we could include. The injury prevention programs reported in the studies included in the current meta-analysis used the same underlying principles of neuromuscular training but varied in the precise way in which these principles were implemented. For example, Gilchrist and colleagues used the Prevent Injury and Enhance Performance (PEP) Program while Pfeiffer and colleagues used the Knee Ligament Prevention

(KLIP) Program [33, 34]. Both programs use proprioceptive and neuromuscular exercises, yet they differ in the specific drills used to accomplish the training (e.g. straight jumps compared to lateral hops over 2 to 6 inch cones). Other programs implemented their own individual training regimens and did not use an established program. This may have limited our ability to detect differences in effectiveness by training components in meta-regression. Data on compliance with the training programs were not consistently reported or readily available. Most papers (56%) analyzed and reported data only on those subjects who completed the study as opposed to all subjects who began the study. Finally, it is possible that injury prevention training has a greater impact on specific sports, such as soccer or handball, where more cutting and pivoting occur. More publications with sport-specific data are needed to evaluate the impact of such programs on sport-specific injury prevention.

We were able to confirm that neuromuscular and proprioceptive training has a protective effect on knee injury incidence, including ACL-specific knee injuries, in athletes. Our analyses showed a statistically significant 27% reduction in knee injury rate and 51% reduction in ACL injury rate specifically. We suggest that athletic departments and coaches consider implementation of neuromuscular and proprioceptive injury prevention programs as a part of regular training given their protective effect on knee injury incidence and the potential to reduce the burden of knee OA [10]. We also suggest that further research focus on elucidating the specific components of neuromuscular and proprioceptive training that contribute to the prevention of knee injury.

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Anterior cruciate ligament injury: Identifying information sources and risk factor awareness among the general population

Abstract

Introduction

Raising awareness on a disorder is important for its prevention and for promoting public health. However, for sports injuries like the anterior cruciate ligament (ACL) injury no studies have investigated the awareness on risk factors for injury and possible preventative measures in the general population. The sources of information among the population are also unclear. The purpose of the present study was to identify these aspects of public awareness about the ACL injury.

Materials and methods

A questionnaire was randomly distributed among the general population registered with a web based questionnaire supplier, to recruit 900 participants who were aware about the ACL injury. The questionnaire consisted of two parts: Question 1 asked them about their sources of information regarding the ACL injury; Question 2 asked them about the risk fac-tors for ACL injury. Multivariate logistic regression was used to determine the information sources that provide a good understanding of the risk factors.

Results and discussion

The leading source of information for ACL injury was television (57.0%). However, the results of logistic regression analysis revealed that television was not an effective medium to create awareness about the risk factors, among the general population. Instead "Lecture by a coach", "Classroom session on Health", and "Newspaper" were significantly more effective in creating a good awareness of the risk factors ($p < 0.001$).

Introduction

Anterior cruciate ligament injury is a critical sports injury, with far reaching consequences. In the United States, there are around 200,000 cruciate ligament injuries annually [1]. Among

Japanese junior high and high school athletes, about 3,000 ACL injuries occur annually, and the injury rate is 0.80 per 1000 athletes [2]. Following the injury, most cases require a reconstruction of the ACL and long-term rehabilitation. Most articles published in recent years, advocate a return to unrestricted sports 6 months or later following ACL reconstruction [3]. Moreover, long-term studies have reported that about 50% of patients develop osteoarthritis of the knee joint, 15 years after an ACL injury, irrespective of the treatment [3,4,5]. Almost all people who participate in any kind of sports activity are at a risk for ACL injury. Therefore, this injury carries a pressing concern in sports medicine, and needs effective prevention strategies.

Previously, many researchers have investigated the mechanisms, risk factors, and prevention methods for ACL injury. Based on the outcomes of these studies, a consensus about ACL injury prevention has recently been reported [3]. Through research, the mechanisms, risk factors, and prevention methods for ACL injury were gradually understood. Almost 80% of the ACL injuries are non-contact in nature. Injuries often occur when landing from a jump, cutting or decelerating [3]. Well-designed injury prevention programs, which focus on proper landing and side-step cutting movement techniques reduce the risk of ACL in athletes, particularly women [3]. However, the incidence of ACL injury did not change between 2005 and 2013 in Japan [2]. One probable reason could be that the existing knowledge did not percolate to the general population, and awareness about the risk factors and prevention methods was insufficient. Thus, disseminating this information is necessary.

For public health, increasing the awareness about a disorder is important for prevention. There have been surveys on public awareness or beliefs about cancer in several countries [6,7,8]. Increasing the awareness through public health policies enables prevention by screening. However, for a sports injury like the ACL injury, no study has investigated the public awareness about its risk factors and prevention methods, to the best of our knowledge. The most effective sources of information for creating awareness are also unclear. If these can be identified, they can be used to spread awareness and adequate understanding.

Therefore, the purpose of this study was to understand how the general population acquires information about ACL injury and to evaluate the most effective medium for understanding the risk factors associated with it. It was hypothesized that the general population acquired information about ACL injury from mass media (television and internal sources); however, these information sources did not necessarily provide a good understanding of the risk factors.

Materials and methods

Study setting

The present study was a cross-sectional analysis of the data obtained from a web-based questionnaire survey. The questionnaire was randomly distributed among the people registered with a web questionnaire supplier (Rakuten Research Inc.), to recruit 900 participants who were aware about ACL injury. According to the power analysis [9], the required sample size for a descriptive study of the dichotomy variable (P = 0.50, W = 0.10, confidence level = 95%) was 384, and required sample size for difference of ratio of dichotomy variable (smaller P_1 = 0.45, difference of P = 0.10, α = 0.05, β = 0.20) was 407. Based on these values, we targeted a sample size of 900. Participants were assigned equitably according to sex (men and women) and age (20's, 30's, 40's, and 50's). While rolling out the survey, a web questionnaire supplier invited 310,325 affiliates to participate in the survey. When the number of respondents who participated and were aware of the ACL injury reached 112 or 113 for each gender in all age groups, and 900 in total, the survey was closed. The survey achieved the desired sample size in 2 days (June 20–21, 2016). Demographic characteristics of the study populations are shown in

Table 1. Demographic characteristics of the study populations.

	Number	Age							
		Mean	Median	SD	[range]				
Total	900	40.2	40.0	10.9	[	20	—	59	]
Males	450	40.5	40.0	11.0	[	20	—	59	]
20—29y	112	25.9	27.0	2.6	[	20	—	29	]
30—39y	112	36.0	36.0	2.5	[	30	—	39	]
40—49y	113	45.3	46.0	2.8	[	40	—	49	]
50—59y	113	54.5	55.0	2.7	[	50	—	59	]
Females	450	40.0	40.0	10.8	[	20	—	59	]
20—29y	112	26.1	27.0	2.7	[	20	—	29	]
30—39y	112	35.2	36.0	3.1	[	30	—	39	]
40—49y	113	44.4	44.0	2.7	[	40	—	49	]
50—59y	113	54.1	54.0	2.7	[	50	—	59	]

Table 1. Participants who agreed to participate in this survey answered the questionnaire voluntarily, and information was collected anonymously, without revealing the identity of any individual participant. The ethical review board of Japan women's college of physical education approved the present study, and the study was conducted based on the principles in the Declaration of Helsinki.

Questionnaire

The questionnaire consisted of one screening question and two main questions (S1 File). The screening question assessed whether the respondent was aware about the ACL injury. If the answer was positive, the questionnaire continued to question 1 and 2. Those who answered in the negative for the screening question were dropped from the survey. Question 1 asked the respondent about the source of information about ACL injury. Participants selected their answers from a list of given options. The options were, "Injury to self", "Injury among family or relatives", "Injury among friends", "Lecture from family", "Lecture from coach", "Classroom session on Health", "Any Classroom session, except on health", "Television", "Magazine", "Comics", "Internet", "Newspaper", and "Poster or flyer in the hospital". Participants were allowed to select multiple answers. Question 2 assessed their knowledge about risk factors for ACL injury. Participants answered "likely to be a risk for ACL injury" or "not likely to be a risk for ACL injury" for each factor. Factors were "Bone geometry", "ACL size", "Joint laxity", "Hormone", "Flexibility", "Foot pronation", "Weakness of front thigh (quadriceps)", "Weakness of back thigh (hamstrings)", "Weakness of hip muscles", "Poor single limb balance", "Increase of weight", "Drinking", "Smoking", "Genu valgum during landing", and "Genu varum during landing". Participants were allowed to select multiple answers. We considered nine factors as risk factors, based on previous studies, and scored the answers for a maximum of nine points. Proven risk factors were "Bone geometry" [10], "ACL size" [10], "Joint laxity" [10], "Hormone" [10], "Foot pronation" [10], "Weakness of back thigh (hamstrings)" [3], "Weakness of hip muscles" [3,11], "Poor single limb balance" [12], and "Genu valgum during landing" [3,10]. We evaluated the validity of this questionnaire and scored points in the colloquium, which consisted of sports medicine physicians, physical therapists and public health personnel. If the sum of the average score and 1SD exceeded nine points, it was considered as a ceiling effect.

Statistical analysis

We allocated participants to two groups: the high understanding group (over 7 points) and low understanding group (under 4 points), based on the score of question 2. Participants scoring 5 or 6 points were excluded from the analysis to accentuate the difference between groups. To determine the source of information, which provides a good understanding of the risk factors, we examined the association between the two groups and each source of information, using chi-square test or Fisher exact test. Moreover, multivariate logistic regression was performed to determine the sources of information that provide a good understanding of the risk factors. Input variables were selected from the significant factors based on the results of the chi-square test or Fisher exact test (p<0.1). Multivariate logistic regression was conducted using forward selection (likelihood ratio), and model chi-square test (p<0.05). Overall percentage of correct information provided, goodness-of-fit (p>0.05), and odds ratio of each factor in the final regression model was calculated. All statistical analyses were performed using SPSS Statistics Version 19.0 for Windows (IBM; Brush Prairie, WA, USA).

Results

Attributes of participants

Total 4248 people responded to the screening question and 900 participants who were aware of the ACL injury completed the survey.

Source of information about ACL injury

Sources of information about ACL injury are shown in Table 2. The most frequent source was "Television" (57.0%), followed by "Injury to friends" (22.4%), "Lecture from coach" (16.6%), and "Internet" (16.3%).

Understanding of the risk factors for ACL injury

The understanding of the risk factors for ACL injury is shown in Table 3. The understanding of "Hormone" and "Foot pronation" was low (20.4% and 28.2%, respectively). The distribution of the score for risk factors is demonstrated in Fig 1. The average score for the risk factors

Table 2. Information source of ACL injury.

Source	Response (n = 900)	Percentage (%) [95%CI]				
Injury to self	62	6.9	[	5.2	—	8.5	]
Injury to family or relative	65	7.2	[	5.5	—	8.9	]
Injury to friends	202	22.4	[	19.7	—	25.2	]
Lecture from family	25	2.8	[	1.7	—	3.9	]
Lecture from coach	149	16.6	[	14.1	—	19.0	]
Classroom session on health	34	3.8	[	2.5	—	5.0	]
Any classroom session, except on health	21	2.3	[	1.3	—	3.3	]
Television	513	57.0	[	53.8	—	60.2	]
Magazine	40	4.4	[	3.1	—	5.8	]
Comics	23	2.6	[	1.5	—	3.6	]
Internet	147	16.3	[	13.9	—	18.7	]
Newspaper	84	9.3	[	7.4	—	11.2	]
Poster or flyer in the hospital	34	3.8	[	2.5	—	5.0	]

Table 3. Responses about risk factors for ACL injury.

	Response (n = 900)	Percentage (%) [95%CI]				
Bone geometry ※	462	51.3	[	48.1	—	54.6	]
ACL size ※	602	66.9	[	63.8	—	70.0	]
Joint laxity ※	613	68.1	[	65.1	—	71.2	]
Hormone ※	184	20.4	[	17.8	—	23.1	]
Flexibility	717	79.7	[	77.0	—	82.3	]
Foot pronation ※	254	28.2	[	25.3	—	31.2	]
Weakness of front thigh (quadriceps)	623	69.2	[	66.2	—	72.2	]
Weakness of back thigh (hamstrings) ※	620	68.9	[	65.9	—	71.9	]
Weakness of hip muscles ※	600	66.7	[	63.6	—	69.7	]
Poor single limb balance ※	637	70.8	[	67.8	—	73.7	]
Increase of weight	723	80.3	[	77.7	—	82.9	]
Drinking	195	21.7	[	19.0	—	24.4	]
Smoking	171	19.0	[	16.4	—	21.6	]
Genu valgum during landing ※	570	63.3	[	60.2	—	66.5	]
Genu varum during landing	566	62.9	[	59.7	—	66.0	]

※The cell done a highlight of by gray was treated as a risk factor.

proven by previous studies was 5.1 (median = 5, s = 2.61) out of a maximum of nine points possible. There was no ceiling effect in this questionnaire. In addition, Cronbach α was 0.80.

Information sources influencing the understanding of risk factors

From the score of question 2, we extracted the high understanding group (n = 348) and the low understanding group (n = 307). Based on the results of the chi-square test or Fisher exact test, "Injury to family or relative", "Lecture from the coach", "Classroom session on Health", "Magazine", "Newspaper", and "Poster or flyer in the hospital" achieved a good score (above 7 points) on the recognition of risk factors. The results of multivariate logistic regression analysis of information sources providing good recognition of risk factors are shown in Table 4. The final regression model included "Lecture from the coach", "Classroom session on Health," and "Newspaper", and provided a significantly good information of risk factors (p<0.001) and had goodness-of fit (= 0.565).

Discussion

The present study investigated the general awareness about ACL injury in Japan using a web-based questionnaire. The main findings of this study were that the most important source of information was television, but this medium was not effective in building awareness in the general population. It was found that people only hear about "ACL injury" from the news or documentaries of television; the awareness of risk factors and prevention is not included in the broadcast. To increase the understanding about ACL injury, dissemination of risk factors and prevention methods through the television is necessary. If the scientific societies or sports organizations can provide correct information through the television, awareness and understanding about ACL injury could be created in the general population.

Other information sources that contributed to the understanding of risk factors were lectures from a coach, classroom session on health, and newspaper. These sources were found to be effective for understanding the injury; however, they were less frequently used. These sources should be utilized to disseminate information. With regard to awareness among
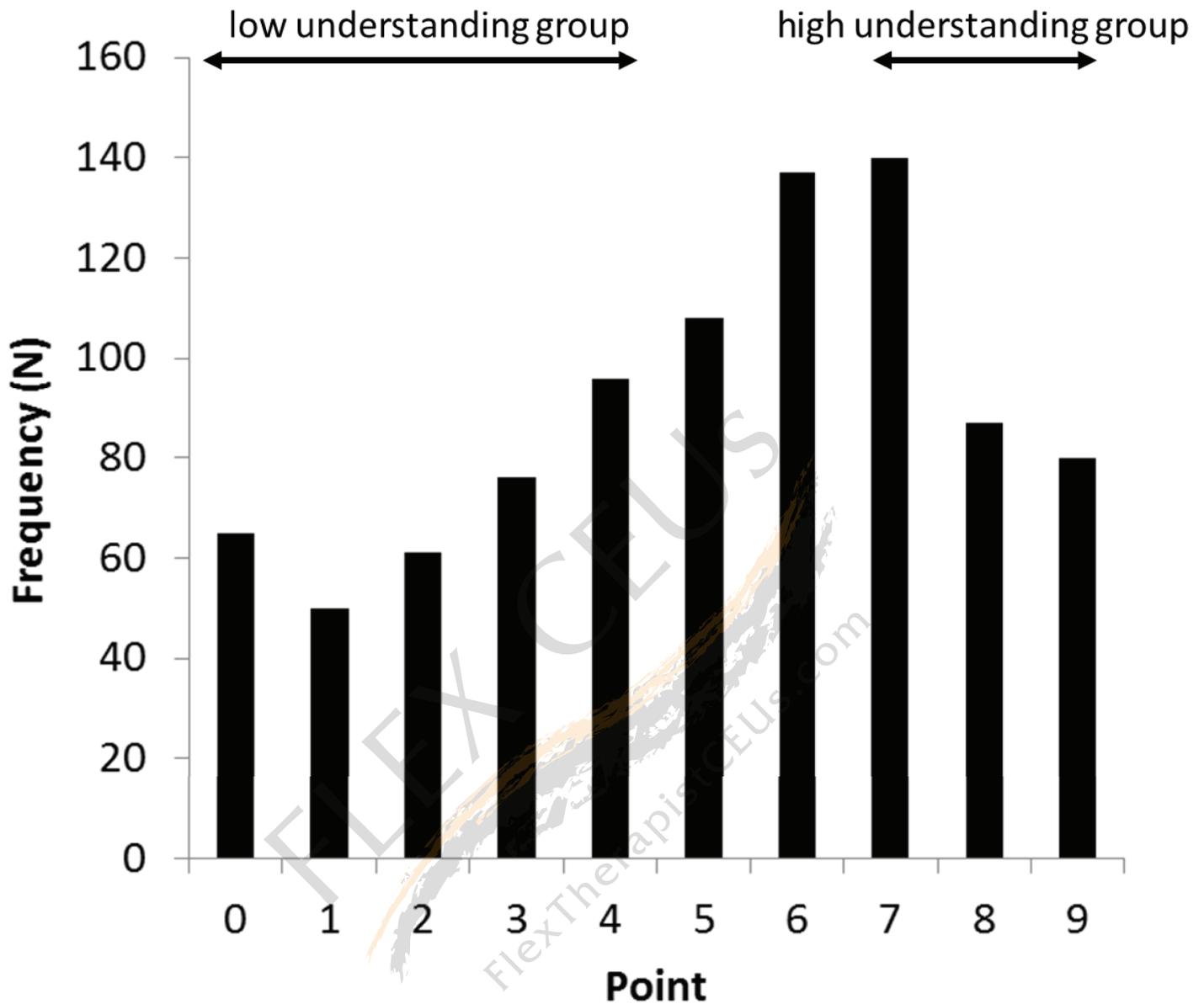
Fig 1. Distribution of scores for risk factors of ACL injury.

Table 4. Results of multivariate logistic regression analysis about the sources of information for awareness of risk factors. (N = 639).

	Coefficients	P value	Odd Ratio [95% CI]				
Lecture from coach	0.671	0.003	1.957	[	1.258	—	3.042	]
Class of Health	1.034	0.036	2.813	[	1.069	—	7.403	]
Newspaper	0.556	0.052	1.743	[	0.996	—	3.052	]
Constant	-0.369	0.000	0.691				

Model chi-square test p<0.001

Overall percentage of correctly predicted: 58.4%

Goodness-of fit (Hosmer and Lemeshow test) = 0.565

coaches, Norcross et al. [13] investigated their knowledge on injury prevention programs and found that 52% reported being aware of injury prevention programs. Interestingly, the most important source of information on injury prevention programs among players was their coaches. Indeed, players were 4.94-times more likely to be aware of prevention programs if their coaches were aware of the programs [14]. To improve the dissemination of injury prevention, all coaches should understand the risk factors and convey this information to the players. In the Japanese junior high school class of health, a chapter is included on injury prevention [15]; however, it does not address a specific injury. We hope that the class of health covers the ACL injury as a representative sports injury. The newspaper is an effective source to disseminate the knowledge; however, the readership is declining. Today, internet could be an effective substitute for a newspaper. In a dissemination study of rugby injury prevention programs [14], social media was also found to be a significant contributor to knowledge among coaches and players. To spread the understanding of ACL injury, an increase in the opportunity to access these information sources through social media is probably necessary.

The limitation of this study is that it used a web-based questionnaire survey. Therefore, we could not identify the population surveyed and participation bias. There is also a possibility of some participants providing false answers. However, this web-based survey is a useful tool for a wide-reaching public investigation in a short period. In addition, to recruit 900 participants who knew of ACL injury, 4248 people were screened, which indicated that 21.2% had heard about it. Although awareness on sports injury or prevention programs among coaches or players has been investigated in previous studies [13,14], few studies have investigated awareness in the general population. Moreover, even fewer studies have done so using a web-based questionnaire. Therefore, these results cannot be compared with other injuries. In the future, additional survey studies are expected as more evidence becomes available.

In conclusion, the results of the present study demonstrated that the most frequent source of information regarding ACL injuries was television, but it did not contribute to the understanding of risk factors. A lecture from the coach, classroom session of health, and newspapers, contributed to the understanding of risk factors. It is recommended to provide improved information through the television or to increase the opportunity for people to attend a lecture by a coach, a classroom session on health, and access newspapers, to increase the awareness and good understanding of ACL injury in the general population.

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