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Exercise-Based Knee and Anterior Cruciate Ligament Injury Prevention

Clinical Practice Guidelines Linked to the International Classification of Functioning, Disability and Health From the Academy of Orthopaedic Physical Therapy and the American Academy of Sports Physical Therapy

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Summary of Recommendations*

REVIEW THE EVIDENCE IN THE SCIENTIFIC LITERATURE FOR EXERCISE-BASED KNEE INJURY PREVENTION PROGRAMS

A Clinicians should recommend use of exercise-based knee injury prevention programs in athletes for the prevention of knee and anterior cruciate ligament (ACL) injuries. Programs for reducing all knee injuries include 11+ and FIFA 11, HarmoKnee, and Knäkontroll; and those used by Emery and Meeuwisse,[14] Goodall et al,[20] Junge et al,[34] LaBella et al,[36] Malliou et al,[41] Olsen et al,[49] Pasanen et al,[51] Petersen et al,[52] and Wedderkopp et al.[78] Programs for reducing ACL injuries include HarmoKnee, Knäkontroll, Prevent Injury and Enhance Performance (PEP), and Sportsmetrics; and those used by Caraffa et al,[5] Heidt et al,[27] LaBella et al,[36] Myklebust et al,[46] Olsen et al,[49] and Petersen et al.[52]

IDENTIFY EXERCISE-BASED KNEE INJURY PREVENTION PROGRAMS THAT ARE EFFECTIVE FOR SPECIFIC SUBGROUPS OF ATHLETES

A Clinicians, coaches, parents, and athletes should implement exercise-based knee injury prevention programs prior to athletic training sessions/practices or games in female athletes to reduce the risk of ACL injuries, especially in female athletes younger than 18 years of age. Programs that should be implemented include PEP, Sportsmetrics, Knäkontroll, HarmoKnee, and those used by Olsen et al[49] and Petersen et al.[52]

A Soccer players, especially women, should use exercise-based knee injury prevention programs to reduce the risk of severe knee and ACL injuries. Programs that could be beneficial for preventing severe knee injuries include PEP, Knäkontroll, and HarmoKnee. Programs that could be beneficial for specifically preventing ACL injuries include those used by Caraffa et al[5] and Sportsmetrics.

B Male and female team handball players, particularly those 15 to 17 years of age, should implement exercise-based knee injury prevention programs. Programs that could be beneficial for preventing knee injuries include those used by Olsen et al[49] and Achenbach et al.[1]

DESCRIBE THE EVIDENCE FOR COMPONENTS, DOSAGE, AND DELIVERY OF EXERCISE-BASED KNEE INJURY PREVENTION PROGRAMS

A Exercise-based knee injury prevention programs used for women should incorporate multiple components, proximal control exercises, and a combination of strength and plyometric exercises.

A Exercise-based knee injury prevention programs should involve training multiple times per week, training sessions that last longer than 20 minutes, and training volumes that are longer than 30 minutes per week.

A Clinicians, coaches, parents, and athletes should start exercise-based knee injury prevention programs in the preseason and continue performing the program through the regular season.

A Clinicians, coaches, parents, and athletes must ensure high compliance with exercise-based knee injury prevention programs, particularly in female athletes.

B Exercise-based knee injury prevention programs may not need to incorporate balance exercises, and balance should not be the sole component of a program.

PROVIDE SUGGESTIONS FOR IMPLEMENTATION OF EXERCISE-BASED KNEE INJURY PREVENTION PROGRAMS

A Clinicians, coaches, parents, and athletes should implement exercise-based knee injury prevention programs in all young athletes, not just those athletes identified through screening as being at high risk for ACL injury, to optimize the numbers needed to treat while reducing cost.

A For the greatest reduction in future medical costs and prevention of ACL injuries, osteoarthritis, and total knee replacements, clinicians, coaches, parents, and athletes should encourage implementation of exercise-based ACL injury prevention programs in athletes 12 to 25 years of age and involved in sports with a high risk of ACL injury.

B Clinicians, coaches, parents, and athletes should support implementation of exercise-based knee injury prevention programs led by either coaches or a group of coaches and medical professionals.

*These recommendations and clinical practice guidelines are based on the scientific literature published prior to October 2017. Internet links to the individual programs (when available) are provided in **TABLE 4**. In addition, the authors of this clinical practice guideline have created 2 videos (one for field sports and one for court sports, available at https://www.jospt.org/doi/suppl/10.2519/jospt.2018.0303) that incorporate key elements of the various programs reviewed in this clinical practice guideline.

List of Abbreviations

11+: an injury prevention program developed originally in association with the medical committee of FIFA (previously known as FIFA 11+)
ACL: anterior cruciate ligament
AE: athlete-exposure
AMSTAR: A Measurement Tool to Assess Systematic Reviews
APTA: American Physical Therapy Association
CI: confidence interval
CPG: clinical practice guideline
EMG: electromyography
FIFA: Fédération Internationale de Football Association (international soccer governing body)
FIFA 11: also known as "the 11," an injury prevention program developed originally in association with the medical committee of FIFA and the predecessor to the 11+
ICD: *International Classification of Diseases*
ICF: *International Classification of Functioning, Disability and Health*
***JOSPT*:** *Journal of Orthopaedic & Sports Physical Therapy*
KLIP: Knee Ligament Injury Prevention program
PEDro: Physiotherapy Evidence Database
PEP: Prevent Injury and Enhance Performance injury prevention program
RCT: randomized controlled trial
SIGN: Scottish Intercollegiate Guidelines Network

Introduction

AIM OF THE GUIDELINE

The Academy of Orthopaedic Physical Therapy and the American Academy of Sports Physical Therapy have an ongoing effort to create evidence-based clinical practice guidelines (CPGs) for orthopaedic and sports physical therapy management and prevention of musculoskeletal impairments described in the World Health Organization's *International Classification of Functioning, Disability and Health* (ICF).[79] This particular guideline focuses on the exercise-based prevention of knee injuries. *Exercise-based prevention* was defined as an intervention requiring the participant(s) to be active and move. This could include physical activity; strengthening; stretching; neuromuscular, proprioceptive, agility, or plyometric exercises; and other training modalities, but excludes passive interventions such as bracing or programs that only involve education. *Knee injuries* were defined as any knee joint pathology including damage to the joint (patellofemoral and/or tibiofemoral), ligaments, meniscus, or patellar tendon. The recommendations can be followed and implemented by athletes, coaches, health and fitness professionals, athletic trainers, physical therapists, physicians, surgeons, and other clinicians.

The objectives of this CPG are as follows.

- Review the evidence in the scientific literature for exercise-based knee injury prevention programs.
- Identify exercise-based knee injury prevention programs that are effective for specific subgroups of athletes.
- Describe the evidence for the components, dosage, and delivery of exercise-based knee injury prevention programs.
- Provide suggestions for the implementation of exercise-based knee injury prevention programs.
- Create a reference publication for athletes, coaches, parents, students, interns, residents, fellows, athletic trainers, orthopaedic and sports physical therapy clinicians, academic instructors, clinical instructors, and physicians and surgeons in orthopaedics and sports regarding the best current practice of exercise-based knee injury prevention programs.

STATEMENT OF INTENT

These guidelines are not intended to be construed or to serve as a standard of medical care. Standards of care are determined on the basis of all clinical data available for an individual athlete/patient and are subject to change as scientific knowledge and technology advance and patterns of care evolve. These parameters of practice should be considered guidelines only. Adherence to them will not ensure a successful outcome in every athlete or patient, nor should they be construed as including all proper methods of care or excluding other acceptable methods of care aimed at the same results. The ultimate judgment regarding a particular injury prevention plan, clinical procedure, or treatment plan must be made based on experience and expertise in light of the presentation of the athlete or patient, the available evidence, available diagnostic and treatment options, and the athlete or patient's values, expectations, and preferences. However, when providing care for athletes/patients, we suggest that significant departures from accepted guidelines should be documented in the athlete/patient's medical records at the time the relevant clinical decision is made.

Methods

The Academy of Orthopaedic Physical Therapy and the American Academy of Sports Physical Therapy appointed content experts with relevant physical therapy, medical, and surgical expertise as developers and authors of the CPG for exercise-based knee injury prevention. These experts were given the task of describing the interventions and evidence for exercise-based knee injury prevention. The authors declared relationships and developed a conflict management plan, which included submitting a Conflict of Interest form to the Academy of Orthopaedic Physical Therapy, APTA, Inc. Funding was provided by the Academy of Orthopaedic Physical Therapy and American Academy of Sports Physical Therapy, and by the APTA to the CPG development team for travel and expenses for CPG development training. The CPG development team maintained editorial independence.

With the assistance of a research librarian (T.H.), the authors systematically searched PubMed, Scopus, SPORTDiscus, CINAHL, and the Cochrane databases for relevant articles. Literature searches were performed in March 2015 and updated in April 2016 and October 2017. Reference lists of included sources were hand searched for additional articles not identified in the searches (see **APPENDIX A** for full search strategies and **APPENDIX B** for search dates and results, available at www.orthopt.org).

Inclusion and exclusion criteria used to select relevant articles were as follows.

INCLUSION CRITERIA

- Exercise-based knee injury prevention
  - Studies needed to expressly state that knee injuries of any kind were the specific target of the program and outcome measure of the study.
  - *Exercise-based prevention* was defined as an intervention requiring the participant to be active and move his or her body. This could include physical activity; strengthening; stretching; neuromuscular, proprioceptive, agility, or plyometric exercises; and other training modalities, but excluded passive interventions such as bracing or programs that only involved education.
  - *Knee injuries* were defined as any knee joint pathology including damage to the joint (patellofemoral and/or tibiofemoral), ligaments, meniscus, or patellar tendon.
- Articles that focused on preventing knee injuries as a whole were included, but so too were articles focused on only one type of knee injury (eg, anterior cruciate ligament [ACL] injuries or patellofemoral pain). This CPG delineates between evidence related to ACL injuries and all knee injuries.
- Mechanism of injury included both contact (injuries as a result of collision with another person or object) and noncontact (injuries that do not involve another individual or object).[17] This CPG discusses contact and noncontact injuries together, unless specifically noted in the text.
- Meta-analyses
- Systematic reviews
- Randomized controlled trials (RCTs)
- Cost-effectiveness studies
- High-level cohort studies (critical appraisal score on the Scottish Intercollegiate Guidelines Network [SIGN] checklist of 5 or greater)
- Published in a peer-reviewed journal
- Able to access full-text article
- Published and accessible in English

EXCLUSION CRITERIA

- Injury prevention programs aimed at preventing all lower extremity injuries
- Injury prevention programs aimed at preventing lower extremity injuries other than knee injuries (eg, ankle injury prevention programs)
- Injury prevention programs aimed at modifying risk factors for knee injuries (eg, modifying peak knee abduction moment)
- Non–exercise-based interventions (eg, prophylactic bracing)
- Case series
- Case-control studies
- Case studies

This guideline focuses on exercise-based knee injury prevention programs, and excludes broader programs aimed at preventing lower extremity injuries. Lower extremity injury prevention programs target a wide range of pathologies, thus selecting different exercises or focusing athlete feedback on joints other than the knee. Further, mechanisms of prevention may also differ. Programs targeting risk factors for knee injuries (eg, programs focused on modifying knee biomechanics during jump landing) were also excluded from this CPG. There are a number of modifiable and nonmodifiable risk factors for knee injuries. However, the magnitude of each risk factor for an athlete can be dependent on many other variables. For example, hormonal changes as a result of menstruation may affect women but not men.[21] Similarly, asymmetries in jump landing have been associated with knee injuries in women[31] but not, to date, in men. As an inter-

Methods *(continued)*

national group of experts in prevention, familiar with the prevention literature as a whole as well as that specific to knee injuries, the authors felt that these were appropriate restrictions.

Components of training programs were defined as different exercise approaches involved in the prevention programs. For example, a program that only involved balance exercises was considered to only have 1 component, whereas a program that involved strengthening and plyometric exercises was considered to have multiple components. Common components include flexibility, strengthening, plyometrics, balance, and agility.

One author (D.S.) screened articles for full-text availability and for publication in English and in peer-reviewed journals. Two authors (A.A. and A.G. or D.L.) then independently screened articles for inclusion based on title and abstract. The authors then discussed their findings. Any article that clearly did not meet inclusion criteria based on title and abstract was excluded at this point, and the full text of any article that the authors were unsure of or that seemed to clearly meet inclusion criteria was then reviewed. Full-text reviews were performed independently by the same authors. The authors met to review their findings, and all disagreements on inclusion/exclusion were resolved by discussion. Consensus was reached on all articles (see **APPENDIX C** for the flow chart of articles and **APPENDIX D** for the citations of articles included in this guideline, available at www.orthopt.org).

All authors were involved in the quality-assessment and data-extraction process. Two authors independently assessed the quality of each article. The A Measurement Tool to Assess Systematic Reviews (AMSTAR) tool was used to assess the quality of meta-analyses and systematic reviews.[58] The Physiotherapy Evidence Database (PEDro) scale was used to assess the quality of RCTs,[75] the SIGN checklist was used to assess the quality of cohort studies,[59] and the Drummond checklist was used to assess the quality of cost-effectiveness analyses.[12] Authors established reliability in the use of each quality-appraisal tool by independently assessing articles not included in the CPG, discussing their scoring, and coming to consensus on areas of disagreement. Discrepancies in quality ratings were resolved through discussion between the 2 authors. Studies that were authored by a reviewer were assigned to an alternate reviewer. Studies with a quality score less than 5 on any scale were considered low quality and were not used in the development of these guidelines[39] (see **APPENDIX E** for quality-assessment scores, available at www.orthopt.org). Recommendations were written based on the included articles and were agreed on by all authors. **APPENDICES A** through **J** are available on the CPG web page at www.orthopt.org.

This guideline was issued in 2018 based on the published literature up to October 2017. This guideline will be considered for review in 2022, or sooner if significant new evidence becomes available. Any updates to the guideline in the interim period will be noted on the Academy of Orthopaedic Physical Therapy website (www.orthopt.org).

LEVELS OF EVIDENCE

Articles were graded according to criteria adapted from the Centre for Evidence-based Medicine, Oxford, United Kingdom for diagnostic, prospective, and therapeutic studies.[56] In 4 teams of 2, authors came to consensus to assign a level of evidence based on the quality assessment of each article (see **APPENDICES F** and **G** for the evidence table and details on procedures used for assigning levels of evidence, available at www.orthopt.org). An abbreviated version of the grading system is provided below.

I	Evidence obtained from systematic reviews, high-quality diagnostic studies, prospective studies, or randomized controlled trials
II	Evidence obtained from systematic reviews, lesser-quality diagnostic studies, prospective studies, or randomized controlled trials (eg, weaker diagnostic criteria and reference standards, improper randomization, no blinding, less than 80% follow-up)
III	Case-control studies or retrospective studies
IV	Case series
V	Expert opinion

GRADES OF EVIDENCE

In teams of 2, the authors developed recommendations based on the strength of evidence, including how directly the studies addressed exercise-based knee injury prevention programs. The strength of the evidence supporting each recommendation was graded according to the previously established methods and is provided on the next page. In developing their recommendations, the authors considered the strengths and limitations of the body of evidence and the health benefits and risks of interventions.

DESCRIPTION OF GUIDELINE REVIEW PROCESS AND VALIDATION

Identified reviewers who are experts in knee injury prevention reviewed the CPG draft for integrity, accuracy, and to ensure that it fully represented the current evidence for the

Methods *(continued)*

GRADES OF RECOMMENDATION		STRENGTH OF EVIDENCE
A	Strong evidence	A preponderance of level I and/or level II studies support the recommendation. This must include at least 1 level I study
B	Moderate evidence	A single high-quality randomized controlled trial or a preponderance of level II studies support the recommendation
C	Weak evidence	A single level II study or a preponderance of level III and IV studies, including statements of consensus by content experts, support the recommendation
D	Conflicting evidence	Higher-quality studies conducted on this topic disagree with respect to their conclusions. The recommendation is based on these conflicting studies
E	Theoretical/ foundational evidence	A preponderance of evidence from animal or cadaver studies, from conceptual models/ principles, or from basic science/bench research supports the recommendation
F	Expert opinion	Best practice based on the clinical experience of the guidelines development team

condition. The guideline draft was also posted for public comment and review on www.orthopt.org, and a notification of this posting was sent to the members of the Academy of Orthopaedic Physical Therapy, APTA, Inc. In addition, a panel of consumer/patient representatives and external stakeholders, such as claims reviewers, medical coding experts, academic educators, clinical educators, physician specialists, and researchers, also reviewed the guideline. All comments, suggestions, and feedback from the expert reviewers, public, and consumer/patient representatives were provided to the authors and editors for consideration and revisions. Guideline development methods, policies, and implementation processes are reviewed at least yearly by the Academy of Orthopaedic Physical Therapy (APTA)'s ICF-Based Clinical Practice Guideline Advisory Panel, including consumer/patient representatives, external stakeholders, and experts in physical therapy practice guideline methodology.

DISSEMINATION AND IMPLEMENTATION TOOLS

In addition to publishing this guideline in the *Journal of Orthopaedic & Sports Physical Therapy* (*JOSPT*), it will be highlighted and posted on the CPG web page of the *JOSPT* and the Academy of Orthopaedic Physical Therapy (APTA) websites. These web pages have unrestricted public access. Implementation tools and associated implementation strategies that will be made available for athletes, coaches, patients, physicians, surgeons, clinicians, educators, payers, policy makers, and researchers are listed in **TABLE 1**.

CLASSIFICATION

The primary International Classification of Diseases-10th Revision (ICD-10) codes and conditions associated with exercise-based knee injury prevention are: **S83.2 Tear of the (medial) (lateral) meniscus of the knee**, **S83.4 Sprain and strain involving (fibular) (tibial) collateral ligament of knee**, **S83.5 Sprain and strain involving (anterior) (posterior) cruciate ligament of knee**, **S83.7 Injury to multiple structures of knee**, **S83.6 Sprain and strain of other unspecified parts of the knee**, and **M22.2 Patellofemoral disorders**.

The primary ICF activities and participation codes associated with exercise-based knee injury prevention are: **d410 Changing basic body positions**, **d450 Walking**, **d4552 Running**, **d4553 Jumping**, **d4559 Moving around**, **specified as direction changes while walking or running**, **d9200 Play**, **d9201 Sports**, and **d9202 Arts and culture**.

ORGANIZATION OF THE GUIDELINES

Topics are arranged in relation to the CPG objectives. For each objective, the summaries of the evidence, levels of evidence, recommendation(s), and grade(s) of recommendation(s) are provided.

Clinical Practice Guidelines

A summary of the content of the training programs and studies on exercise-based knee injury prevention programs that met the inclusion criteria for this CPG is found in **TABLES 2**, **3**, and **4**.

OBJECTIVE

Review the evidence in the scientific literature for exercise-based knee injury prevention programs. Evidence includes systematic reviews and meta-analyses that look at prevention programs across populations (**APPENDIX H**, available at www.orthopt.org, and **TABLE 3**).

Evidence

I Three meta-analyses have examined exercise-based knee injury prevention programs across populations.[9,18,57] One meta-analysis examined the efficacy in reducing all knee injuries as well as reducing ACL injuries specifically,[9] and 2 focused only on ACL injuries.[18,57] All of the studies included in these meta-analyses involved athletes (sporting or tactical/military), with participants being men and women of different ages and races, as well as with different sports and skill levels.

The exercise-based prevention programs included in these analyses employed a number of different intervention strategies, from neuromuscular and proprioceptive training to strengthening, stretching, and plyometric exercises. Many of these programs employed more than one of these strategies, and gave participants feedback on their form during exercises, particularly jump landings.[9,18,57]

The pooled incidence rate ratio, based on 19 studies (n = 19 143), indicated that exercise-based prevention programs are effective in reducing the incidence of knee injuries (incidence rate ratio = 0.73; 95% confidence interval [CI]: 0.61, 0.87).[9] Programs in the meta-analysis showing efficacy in reducing knee injuries include FIFA (Fédération Internationale de Football Association) 11+[25,61] and FIFA 11 ("The 11"),[73] HarmoKnee,[35] and Knäkontroll[77]; and those used by Emery and Meeuwisse,[14] Goodall et al,[20] Junge et al,[34] LaBella et al,[36] Malliou et al,[41] Olsen et al,[49] Pasanen et al,[51] Petersen et al,[52] and Wedderkopp et al.[78]

Pooled rate and risk ratios from the 3 meta-analyses[9,18,57] examining the impact of exercise-based knee injury prevention programs on incidence of primary ACL injuries indicate that these programs are effective.[18,57] Gagnier et al[18] examined 14 studies (n = 27 000) and found a pooled rate ratio of 0.46 (95% CI: 0.36, 0.60). Sadoghi et al[57] examined 8 studies (n = 10 839) and found a pooled risk ratio of 0.38 (95% CI: 0.20, 0.72). Donnell-Fink et al[9] examined 14 studies (n = 17 735) and found a rate ratio of 0.49 (95% CI: 0.29, 0.85). The authors of this study narrowed their analysis to examine noncontact injuries, and found a rate ratio of 0.51 (95% CI: 0.30, 0.88). Programs in the meta-analysis showing efficacy in reducing ACL injuries include Caraffa et al,[5] HarmoKnee,[35] Heidt et al,[27] Knäkontroll,[77] LaBella et al,[36] Myklebust et al,[46] and Olsen et al,[49] Prevent Injury and Enhance Performance (PEP),[19] Petersen et al,[52] and Sportsmetrics.[29]

Evidence Synthesis

There is strong evidence for the benefits of exercise-based knee injury prevention programs, including reduction in risk for all knee injuries and for ACL injuries specifically, with little risk of adverse events and minimal cost.

Recommendation

A Clinicians should recommend use of exercise-based knee injury prevention programs in athletes for the prevention of knee and ACL injuries. Programs for reducing all knee injuries include 11+ and FIFA 11, HarmoKnee, and Knäkontroll; and those used by Emery and Meeuwisse,[14] Goodall et al,[20] Junge et al,[34] LaBella et al,[36] Malliou et al,[41] Olsen et al,[49] Pasanen et al,[51] Petersen et al,[52] and Wedderkopp et al.[78] Programs for reducing ACL injuries include HarmoKnee, Knäkontroll, Prevent Injury and Enhance Performance (PEP), and Sportsmetrics; and those used by Caraffa et al,[5] Heidt et al,[27] LaBella et al,[36] Myklebust et al,[46] Olsen et al,[49] and Petersen et al.[52]

OBJECTIVE

Identify exercise-based knee injury prevention programs that are effective for specific subgroups of athletes. Evidence includes systematic reviews, meta-analyses, and cohort studies that specifically delineate populations (**APPENDICES I** and **J**, available at www.orthopt.org).

Evidence

Men

II One systematic review examined the effects of exercise-based prevention programs on ACL injuries in only men.[2] The review by Alentorn-Geli et al[2] found that studies of exercise-based knee prevention programs in men were primarily performed on soccer teams. The review identified 1 program successful in reducing ACL injury rates. The Caraffa et al[5] program reported ACL injury rates in the intervention group of 0.15 ACL injuries per team per year and in the control group of 1.15 ACL injuries per team per year. The review also identified a study by Grooms et al[25] that examined the 11+ program. Using a 1-season historical control, Grooms et al[25] did not observe an ACL injury in either the control or intervention season.

Women

I Three meta-analyses indicate that, in women, exercise-based injury prevention programs are effective in reducing the risk of all ACL injuries, with pooled odds ratios ranging from 0.40 to 0.64.[45,72,80] More specifically, when reporting only noncontact ACL injuries, the pooled odds ratio was 0.38.[72,80]

Programs identified by meta-analyses[45,72,80] as being effective in reducing the risk for ACL injuries in women were the PEP, Sportsmetrics, Knäkontroll, and HarmoKnee, as well as the programs used in the studies by Myklebust et al[46] and Petersen et al.[52] Common themes of these successful programs were use of multiple types of exercises, participation during the preseason or preseason and in-season, performance prior to training sessions/practices or games, and an emphasis on what is thought to be optimal lower extremity alignment.[19,27,29,35,36,42,46,49,52,63,77]

Two programs were identified as being ineffective at preventing ACL injuries.[72,80] The Knee Ligament Injury Prevention (KLIP) exercise-based knee injury prevention program, used by Pfeiffer et al[54] with high school–aged adolescent girls and women, was used after practices and games. Despite an odds ratio of 2.05, suggesting a greater risk of incurring a noncontact ACL injury for the athletes in their intervention group, the wide 95% CI (0.21, 21.7) indicates a lack of statistical significance. Söderman et al[60] found that a greater percentage of athletes in their intervention group incurred noncontact ACL injuries (intervention, 6.5%; control, 1.3%; no *P* value reported) or other knee injuries, including those to the combined ACL and medial collateral ligament, medial collateral ligament, lateral collateral ligament, posterior cruciate ligament, and contusions (intervention, 12.9%; control, 7.7%; no *P* value reported), than those in their control group. Unlike the effective programs that involved multiple exercise modalities, the Söderman et al[60] program only involved balance-board training.

I Adolescent female athletes seem to gain the most benefit from exercise-based knee injury prevention programs.[45,68,80] Two meta-analyses examined the effect of age, finding that girls under 18 years of age have a greater reduction in ACL injuries (odds ratio = 0.27-0.28) compared to women over 18 years of age (odds ratio = 0.78-0.84).[45,80] Analyzing age based on tertiles, Myer et al[45] found a statistically significant reduction in ACL injuries for the youngest group, but not for the older 2 groups: ages 14 to 18 years (odds ratio = 0.28; 95% CI: 0.18, 0.42), ages 18 to 20 years (odds ratio = 0.48; 95% CI: 0.21, 1.07), and ages older than 20 years (odds ratio = 1.01; 95% CI: 0.62, 1.64).[45] An additional study analyzed age in quartiles. Sugimoto et al[68] found that female athletes 14 to 18 years of age had greater reduction in ACL injury incidence (odds ratio = 0.29; 95% CI: 0.19, 0.44; $P = .01$) compared to those younger than 14 years of age (odds ratio = 0.29; 95% CI: 0.01, 7.09; $P = .45$), 18 to 20 years of age (odds ratio = 0.48; 95% CI: 0.21, 1.07; $P = .07$), and older than 20 years of age (odds ratio = 1.01; 95% CI: 0.62, 1.64; $P = .97$).

Soccer

I A meta-analysis of RCTs found a protective effect of exercise-based knee injury prevention programs in soccer players (men and women) for knee injuries (relative risk = 0.74; 95% CI: 0.55, 0.98). The study found a reduction in ACL injuries, though this decrease in incidence was not statistically significant (relative risk = 0.66; 95% CI: 0.33, 1.32).[22] Three prevention programs, however, were successful in significantly decreasing the incidence of ACL injuries in soccer players when compared to a control group (PEP,[42] Knäkontroll,[77] and the program used by Caraffa et al[5]).

Three individual studies included in this CPG (using the PEP, Knäkontroll, and HarmoKnee programs) examined the incidence of knee injuries.[29,35,77] While all 3 studies showed a decrease in the incidence of knee injuries,[29,35,77] the reduction was only statistically significant with the Knäkontroll program.[77] All 7 individual studies included in this CPG that examined ACL injury incidence in soccer players (PEP, Knäkontroll, KLIP, the program by Caraffa et al,[5] Sportsmetrics) found a decrease in ACL injuries.[19,29,35,42,54,77]

II In female soccer players (n = 4564) between the ages of 12 and 17 years, the Knäkontroll program reduced ACL injuries in the intervention group by 64% (rate ratio = 0.36; 95% CI: 0.15, 0.85) and severe knee injuries by 30% (rate ratio = 0.70; 95% CI: 0.42, 1.18).[77]

Two studies examined the efficacy of the PEP program in reducing ACL injuries in female soccer players. Mandelbaum et al[42] examined adolescent girls and women aged 14 to 18 years and found an 89% decrease (rate ratio = 0.11; 95% CI: 0.03, 0.48) in ACL injuries compared to age- and skill-matched control athletes in the first season of the PEP program, and a 74% decrease (rate ratio = 0.26; 95% CI: 0.09, 0.85) in the second season of use. Gilchrist et al[19] examined college-aged women and found lower, but nonsignificant, differences in rates of ACL injuries in their intervention (0.20/1000 athlete-exposures [AEs]) compared to their control (0.34/1000 AEs) group (*P* = .20).[19] The results were similar (lower but nonsignificant rates) when they examined noncontact ACL injuries specifically (intervention, 0.06/1000 AEs; control, 0.19/1000 AEs). There was a higher rate, though not significant, of overall knee injuries in their intervention group (1.14/1000 AEs) compared to their control group (1.10/1000 AEs, *P* = .86).

II Studies that have examined female soccer and team handball players have shown effectiveness in reducing ACL injuries (soccer: odds ratio = 0.32; 95% CI: 0.19, 0.56; team handball: odds ratio = 0.54; 95% CI: 0.30, 0.97).[80] However, making direct comparisons of effectiveness between sports needs to be done with caution, because the exercise-based knee injury prevention programs used in each cohort were not identical.

Team Handball

II Olsen et al[49] found significant reductions in acute knee injuries (relative risk = 0.45; 95% CI: 0.25, 0.81) and knee ligament injuries (relative risk = 0.20; 95% CI: 0.06, 0.70) in 16- to 17-year-old male and female team handball athletes after implementing an exercise-based knee injury prevention program. However, they noted no change in meniscal injuries (relative risk = 0.27; 95% CI: 0.06, 1.28).

II Achenbach et al[1] found significant reductions in severe (injuries that cause 28 or more days of absence from sport) knee injuries (odds ratio = 0.11; 95% CI: 0.01, 0.90; *P* = .02) in 15- to 17-year-old male and female team handball athletes.

II In female team handball players, Myklebust et al[46] did not find a significant decrease in ACL injuries after performing an exercise-based knee injury prevention program for 2 seasons. However, when comparing teams that were compliant with the program (performed the intervention 15 or more times over the course of the season, with at least 75% of players participating) to the teams that were not compliant, they found a significant decrease in ACL injuries among the compliant elite team handball athletes (odds ratio = 0.06; 95% CI: 0.01, 0.54).

Basketball

II There is conflicting evidence on the effectiveness of exercise-based knee injury prevention programs in female basketball players. Hewett et al[29] observed fewer knee ligament injuries (sprain/tear leading to greater than 5 consecutive days of absence from sport) in their female basketball intervention group. Although this was not a statistically significant difference in incidence (intervention, 0.42 injuries/1000 AEs; control, 0.48 injuries/1000 AEs; *P* = .17), it was a positive trend following their 6-week, preseason, 60- to 90-minute plyometric-based program. Female basketball players who performed their intervention had significantly fewer noncontact knee injuries compared to control female basketball players (*P* = .02). In contrast, Pfeiffer et al[54] observed a 4-fold greater risk of noncontact ACL injury in their intervention group compared to the control group (intervention, 0.48 ACL injuries per 1000 AEs; control, 0.11/1000 AEs) following their 15- to 20-minute program that was performed after training sessions.

Volleyball

II No conclusions can be drawn with regard to exercise-based knee injury prevention programs in female volleyball players. Two studies included volleyball players, but neither study observed the outcome of interest (serious knee injury or ACL injury) in either the intervention or the control group.[29,54]

Evidence Synthesis

There is evidence of important benefits of exercise-based knee injury prevention programs, including reduction of risk for knee and ACL injuries, with little risk of adverse events and minimal cost. However, the guideline development group identified gaps in evidence and recommends that researchers and clinicians should further evaluate the efficacy of exercise-based knee injury prevention programs in men of various ages playing sports. Additionally, researchers and clinicians should further evaluate the efficacy of exercise-based knee injury prevention programs in basketball and volleyball athletes. Although large-scale prospective trials or RCTs are costly, the benefits of identifying programs effective in reducing knee injuries in various sports outweigh these financial costs.

Recommendations

A Clinicians, coaches, parents, and athletes should implement exercise-based knee injury prevention programs prior to athletic training sessions/practices or games in female athletes to reduce the risk of ACL injuries, especially in female athletes younger than 18 years of age. Programs that should be implemented include PEP, Sportsmetrics, Knäkontroll, HarmoKnee, and those used by Olsen et al[49] and Petersen et al.[52]

A Soccer players, especially women, should use exercise-based knee injury prevention programs to reduce the risk of severe knee and ACL injuries. Programs that could be beneficial for preventing severe knee injuries include PEP, Knäkontroll, and HarmoKnee.

Programs that could be beneficial for specifically preventing ACL injuries include those used by Caraffa et al[5] and Sportsmetrics.

B Male and female team handball players, particularly those 15 to 17 years of age, should implement exercise-based knee injury prevention programs. Programs that could be beneficial for preventing knee injuries include those used by Olsen et al[49] and Achenbach et al.[1]

OBJECTIVE

Describe the evidence for components, dosage, and delivery of exercise-based knee injury prevention programs.

Evidence

Components

I Exercise-based injury prevention programs are effective in reducing ACL injuries in young women when the programs incorporate multiple exercise components.[67] Programs with more than 1 component resulted in ACL injury reductions (odds ratio = 0.32; 95% CI: 0.22, 0.46). In contrast, programs with only a single exercise component did not result in a significant reduction of injuries (odds ratio = 1.15; 95% CI: 0.70, 1.89).[67]

I Exercise-based knee injury prevention programs in women that include proximal control exercises, such as trunk/core strengthening and stability exercises, led to significantly lower ACL injury rates (odds ratio = 0.33; 95% CI: 0.23, 0.47). In contrast, programs that did not include proximal control exercises did not reduce injury rates (odds ratio = 0.95; 95% CI: 0.60, 1.50).[67]

II Programs that incorporate both plyometric and strengthening components are more effective at reducing ACL injuries in women than programs without both of these components.[64,67,80] Stevenson et al[64] noted that studies that have demonstrated statistically significant decreases in ACL injuries have all included strengthening, flexibility, and plyometric components in their programs (PEP, Sportsmetrics, and the program used by Myklebust et al[46]),[19,29,42] and only 1 program with a plyometric component (the KLIP program used after training sessions and games)[54] has not resulted in a decrease in ACL injuries. When strength and plyometrics are examined separately, Sugimoto et al[67] found that there was no significant difference in ACL injury risk between programs with and without plyometric components. However, when comparing programs with and without strengthening components, there was a significant reduction in the number of ACL injuries only in those programs with strengthening exercises (odds ratio = 0.32; 95% CI: 0.23, 0.46). Those without strengthening exercises failed to reduce ACL injuries (odds ratio = 1.02; 95% CI: 0.63, 1.64).[67]

II Programs without balance training components (Sugimoto et al[67]: odds ratio = 0.34; CI: 0.20, 0.56; Yoo et al[80]: odds ratio = 0.27; CI: 0.14, 0.49) are effective in preventing ACL injuries in women. There are differing results regarding whether programs with balance training components are effective (Sugimoto et al[67]: odds ratio = 0.59; CI: 0.42, 0.83; Yoo et al[80]: odds ratio = 0.63; CI: 0.37, 1.09). Taylor et al[72] found that as the duration of time within a program spent performing balance exercises increased, the protective effect of the program decreased.

One program described by Söderman et al[60] was included in all 3 meta-analyses examining the components of prevention programs.[67,72,80] Söderman et al[60] only included balance exercises and observed a greater rate of ACL injuries in the intervention group.

II Sadoghi et al[57] performed a meta-regression to determine the factors that influence the effect of an exercise-based knee injury prevention program in women. They found that use of balance boards (P = .71), use of video assistance (P = .91), duration of follow-up (P = .44), and year of study publication (P = .36) did not influence a program's ACL injury risk reduction.

Dosage and Delivery

I Gagnier et al[18] performed a meta-analysis including men and women that indicated that programs with a longer duration (greater than 14 months; incidence rate ratio estimate = 0.41; 95% CI: 0.20, 0.84; P =.01), more hours of training per week (0.75 hours or more per week; incidence rate ratio estimate = 0.38; 95% CI: 0.18, 0.77; P<.01), higher compliance (64% or greater; incidence rate ratio estimate = 0.39; 95% CI: 0.17, 0.89; P = .03), and no participant dropout (incidence rate ratio estimate = 0.30; 95% CI: 0.15, 0.62; P<.01) were more effective at reducing ACL injury incidence than programs that did not have these qualities.

I Sugimoto et al[66] performed a meta-analysis and subgroup analysis on clinical trials and evaluated potential dosage effects of exercise-based injury prevention training for ACL injury reduction in female athletes. Exercise-based injury prevention programs with a high volume during the season (30 or more minutes per week) had an odds ratio of 0.32 (95% CI: 0.19, 0.52) in reducing ACL injuries, compared to those with moderate (15-30 minutes per week: odds ratio = 0.46; 95% CI: 0.21, 1.03) and low volumes (up to 15 minutes per week: odds ratio = 0.66; 95% CI: 0.43, 0.99). Programs that lasted 20 minutes or less per session had an odds ratio of 0.61 (95% CI: 0.41, 0.90) in reducing ACL injuries, whereas programs that lasted longer than 20 minutes per session had an odds ratio of 0.35 (95% CI: 0.23, 0.53). Exercise-based injury prevention programs implemented multiple times per week had an odds ratio of 0.35 (95% CI: 0.23, 0.53) in reducing ACL injuries compared to programs that only used training once a week, which had an odds ratio of 0.62 (95% CI: 0.41, 0.94).

I Donnell-Fink et al[9] examined men and women, comparing preseason-only and preseason-plus-in-season programs to in-season-only programs, and found lower risk for knee injuries when preseason was included (preseason/preseason-plus-in-season incidence rate ratio = 0.24; in-season-only rate ratio = 0.75; no CIs presented; P<.01). They did not find a significant result with this same comparison for ACL injuries specifically (preseason/preseason-plus-in-season incidence rate ratio = 0.32; in-season-only rate ratio = 0.57; P = .33).[9]

In women, exercise-based knee injury prevention programs that began in the preseason and continued throughout the season were effective (odds ratio = 0.54; 95% CI: 0.30, 0.97) in reducing ACL injuries.[80] Programs in-season only (odds ratio = 0.32; 95% CI: 0.17, 0.59) had a lower odds ratio than programs in the preseason and in-season. Programs in the preseason only (odds ratio = 0.35; 95% CI: 0.10, 1.21) were not effective in reducing ACL injuries.[80]

I Sugimoto et al[68] performed a meta-regression examining the "synergistic effects" of components of exercise-based knee injury prevention programs that they deemed key to optimizing ACL injury prevention. They grouped age in tertiles (14-18 years, 18-20 years, 20 years or older), dosage was dichotomized (20 minutes or less per session, greater than 20 minutes per session), frequency was dichotomized (once per week, multiple times per week), number of exercises was dichotomized (programs made up of only 1 exercise component, programs made up of multiple components), and verbal feedback to athletes on their form was dichotomized (verbal feedback given, no verbal feedback). Points were assigned to groups based on previously reported odds ratios, with higher points given to groupings that demonstrated lower odds ratios (greater ACL injury reduction). Groups with the highest points were those aged 14 to 18 years, programs greater than 20 minutes in duration, programs performed multiple times per week, and programs with multiple exercise components. The results indicated an odds ratio of 0.83 ($\beta 1$ = −0.29; 95% CI: −0.33, −0.03; P = .03), or 17% lower odds of sustaining an ACL injury if one of these highest-point groups was present.

Compliance

I Sugimoto et al[69] performed a meta-analysis of studies involving female soccer, basketball, volleyball, and team handball athletes, concluding that higher rates of compliance with exercise-based injury prevention programs were associated with lower rates of ACL injury incidence among adolescent female athletes. The authors found that when compliance was dichotomized (greater than versus less than 42.5% overall compliance rate*), the incidence rate in the high-compliance group was 73% lower (incidence rate ratio = 0.27; 95% CI: 0.07, 0.80). When divided into tertiles (greater than 66.6%, 33.3%-66.6%, less than 33.3% overall compliance), the high-compliance group had 82% lower ACL injury incidence (incidence rate ratio = 0.18; 95% CI: 0.02, 0.77) than the medium- and low-compliance groups. The authors reported that a potential inverse dose-response relationship exists between compliance with an exercise-based injury prevention program and the incidence of ACL injury in adolescent female athletes. **Overall compliance rate* was defined as the attendance rate multiplied by the compliance rate, with *attendance rate* defined as the number of participants who completed the minimum amount of session criteria in the study divided by the total number of participants in the intervention group. *Compliance rate* was defined as the number of sessions completed in the study divided by the maximum number of sessions offered to the intervention group.

II Studies of female soccer players, with data adjusted for compliance, found greater knee injury incidence reductions in athletes who were compliant with the exercise-based prevention programs.[35,77] Kiani et al,[35] using the HarmoKnee program, found a 77% lower incidence of knee injuries (rate ratio = 0.23; 95% CI: 0.04, 0.83) and a 90% lower incidence of noncontact knee injuries (rate ratio = 0.10; 95% CI: 0.00, 0.70). These reductions in knee injury risk decreased further when they were adjusted for compliance (removal of 3 teams that performed the intervention with less than 75% compliance, leaving 45 teams in the intervention group). Athletes who were compliant with the HarmoKnee program had an 83% reduction in knee injury incidence (rate ratio = 0.17; 95% CI: 0.04, 0.64) and a 94% decrease in noncontact knee injuries (rate ratio = 0.06; 95% CI: 0.01, 0.46).

II Waldén et al,[77] using the Knäkontroll program in a cluster RCT, found an overall 64% decrease in ACL injury incidence (rate ratio = 0.36; 95% CI: 0.15, 0.85) in their intervention group compared to controls, but when they examined only their compliant players (defined as players having performed the intervention once per week on average), they found an 83% reduction in ACL injury rate (rate ratio = 0.17; 95% CI: 0.05, 0.57). They also found that compliant players had an 82% reduction in the rate of severe knee injuries (rate ratio = 0.18; 95% CI: 0.07, 0.45) and a 47% reduction in the rate of acute knee injuries (rate ratio = 0.53; 95% CI: 0.30, 0.94).

Hägglund et al[26] performed a subanalysis on the same RCT.[77] Teams and players in the intervention group (184 teams, 2471 players) were stratified into tertiles of compliance (low, intermediate, and high) based on their mean number of weekly injury prevention program training sessions during the season. High player compliance (mean, 89% compliance rate) resulted in an 88% reduction in ACL injury rate compared with low compliance (mean, 63% compliance rate). Intermediate compliance (mean, 82% compliance rate) and high compliance reduced acute knee injury by 72% to 90% compared to low compliance. Low-compliance players had higher rates of ACL injuries than the control players.

Evidence Synthesis

There is evidence of important benefits of exercise-based knee injury prevention programs, including reduction of risk for knee and/or ACL injuries, with little risk of adverse events and minimal cost.

Recommendations

A Exercise-based knee injury prevention programs used for women should incorporate multiple components, proximal control exercises, and a combination of strength and plyometric exercises.

A Exercise-based knee injury prevention programs should involve training multiple times per week, training sessions that last longer than 20 minutes, and training volumes that are longer than 30 minutes per week.

A Clinicians, coaches, parents, and athletes should start exercise-based knee injury prevention programs in the preseason and continue performing the program throughout the regular season.

A Clinicians, coaches, parents, and athletes must ensure high compliance with exercise-based knee injury prevention programs, particularly in female athletes.

B Exercise-based knee injury prevention programs may not need to incorporate balance exercises, and balance should not be the sole component of a program.

OBJECTIVE

Provide suggestions for implementation of exercise-based knee injury prevention programs.

Evidence

I Grindstaff et al[24] performed a systematic review to determine the number of athletes needed to treat and the relative risk reduction in noncontact ACL injuries associated with exercise-based knee injury prevention programs. The sample included female soccer, basketball, and team handball athletes using 5 different prevention programs that varied in their exercise components. Frequency of training ranged from 3 times per week in the preseason to 1 to 3 times per week during the season. They reported that to prevent 1 noncontact ACL injury during a sports season, 89 athletes (95% CI for number needed to benefit: 66, 136) would have to participate in a prevention program. The relative risk reduction for noncontact ACL injuries was 70% (95% CI: 54%, 80%) in athletes involved in a prevention program.

I An updated systematic review was published by Sugimoto et al,[70] examining 12 studies (including all 5 studies reviewed by Grindstaff et al[24]), to determine the effectiveness of exercise-based injury prevention programs designed to reduce ACL injury risk and noncontact ACL injury risk in female athletes. Sugimoto et al[70] reported that to prevent 1 ACL injury during a sports season, 120 athletes (95% CI for number needed to benefit: 74, 316) would need to participate in an exercise-based knee injury prevention program. The relative risk reduction for ACL injury was 43.8% (95% CI: 28.9%, 55.5%) in athletes involved in the prevention programs. Over the course of 1 season, to prevent 1 noncontact ACL injury, 108 athletes (95% CI for number needed to benefit: 86, 150) would have to participate in an exercise-based knee injury prevention program, with a relative risk reduction for noncontact ACL injury of 73.4% (95% CI: 62.5%, 81.1%) in athletes involved in the prevention programs.

I Lewis et al[38] performed a cost analysis of 4 hypothetical strategies for implementing exercise-based ACL injury prevention programs across Australia. Using a prevention program similar to those in the literature,[19,32,53,54] performed 3 times per week for 20 minutes and supervised by coaches and medical staff, the study examined the resulting costs if implemented across Australia in 12- to 25-year-olds involved in high-risk sports, 18- to 25-year-olds involved in high-risk sports, 12- to 17-year-olds involved in high-risk sports, or all adolescents aged 12 to 17 years involved in any sport. *High-risk sports* were defined as rugby, Australian rules football, netball, soccer, basketball, and skiing. The authors found that the implementation strategy involving training 12- to 25-year-olds involved in high-risk sports had the highest break-even value (the future health care costs avoided) of $693 per person, followed by training 18- to 25-year-olds in high-risk sports (break-even cost, $401), 12- to 17-year-olds in high-risk sports ($370), and all 12- to 17-year-olds in sports ($102). The analysis also found that the strategy of training 12- to 25-year-olds in high-risk sports would prevent the most ACL injuries, with the lowest number needed to treat, as well as prevent the highest number of future knee injuries and total knee replacements (prevented 3764 ACL injuries [number needed to treat, 27], 842 knee osteoarthritis cases, and 584 total knee replacements per 100 000 treated). Training 18- to 25-year-olds in high-risk sports prevented the next largest number of ACL injuries and resulted in the smallest number needed to treat (prevented 2303 ACL injuries [number needed to treat, 43], 511 osteoarthritis cases, and 353 total knee replacements per 100 000 treated), followed by 12- to 17-year-olds in high-risk sports (prevented 2021 ACL injuries [number needed to treat, 49], 457 osteoarthritis cases, and 317 total knee replacements per 100 000 treated), and 12- to 17-year-olds in all sports (prevented 526 ACL injuries [number needed to treat, 190], 119 osteoarthritis cases, and 83 total knee replacements per 100 000 treated).

II Swart et al[71] performed a cost-effectiveness analysis on prevention and screening programs for ACL injuries in young athletes who participated in pivoting and cutting sports. They reported that an exercise-based ACL injury prevention program performed by all athletes could reduce the incidence of ACL injury from 3% per season to 1.1% per season, while a screening program that targeted high-risk athletes could reduce ACL injury incidence from 3% per season to 1.8% per season. On a per-case basis, the average cost of the universal training strategy was $100 lower than no training and $25 lower than the screening and training strategy.

II Pfile and Curioz[55] performed a number-needed-to-treat analysis examining exercise-based ACL injury prevention programs led by coaches versus programs led by what they termed a *mixed leadership group* (ie, coaches, physical therapists, and/or athletic trainers). Programs led by a mixed leadership group had a lower number needed to benefit (120 athletes needed to treat to prevent 1 ACL injury; 95% CI: 73, 303), but a slightly higher relative risk reduction of 48.2% (95% CI: 22%, 65%), compared to coach-led programs, which had a number needed to benefit of 131 (95% CI: 98, 196) and a relative risk reduction of 58.4% (95% CI: 40%, 71%).

Evidence Synthesis

There is no increase in risk of adverse events when all athletes perform prevention programs compared to only athletes screened as high risk, and there is no harm in performing prevention programs. Although cost may minimally increase (depending on the program) as more athletes participate, the small increase in program costs is likely outweighed by long-term health care costs and by the reduction in ACL injuries.

Recommendation

A Clinicians, coaches, parents, and athletes should implement exercise-based knee injury prevention programs in all young athletes, not just those athletes identified through screening as being at high risk for ACL injury, to optimize the numbers needed to treat while reducing costs.

A For the greatest reduction in future medical costs and prevention of ACL injuries, osteoarthritis, and total knee replacements, clinicians, coaches, parents, and athletes should encourage implementation of exercise-based ACL injury prevention programs in athletes 12 to 25 years of age and involved in sports with a high risk of ACL injury.

B Clinicians, coaches, parents, and athletes should support implementation of exercise-based knee injury prevention programs led by either coaches or a group of coaches and medical professionals.

The recommendations made in this guideline are summarized in **FIGURES 1** and **2**.

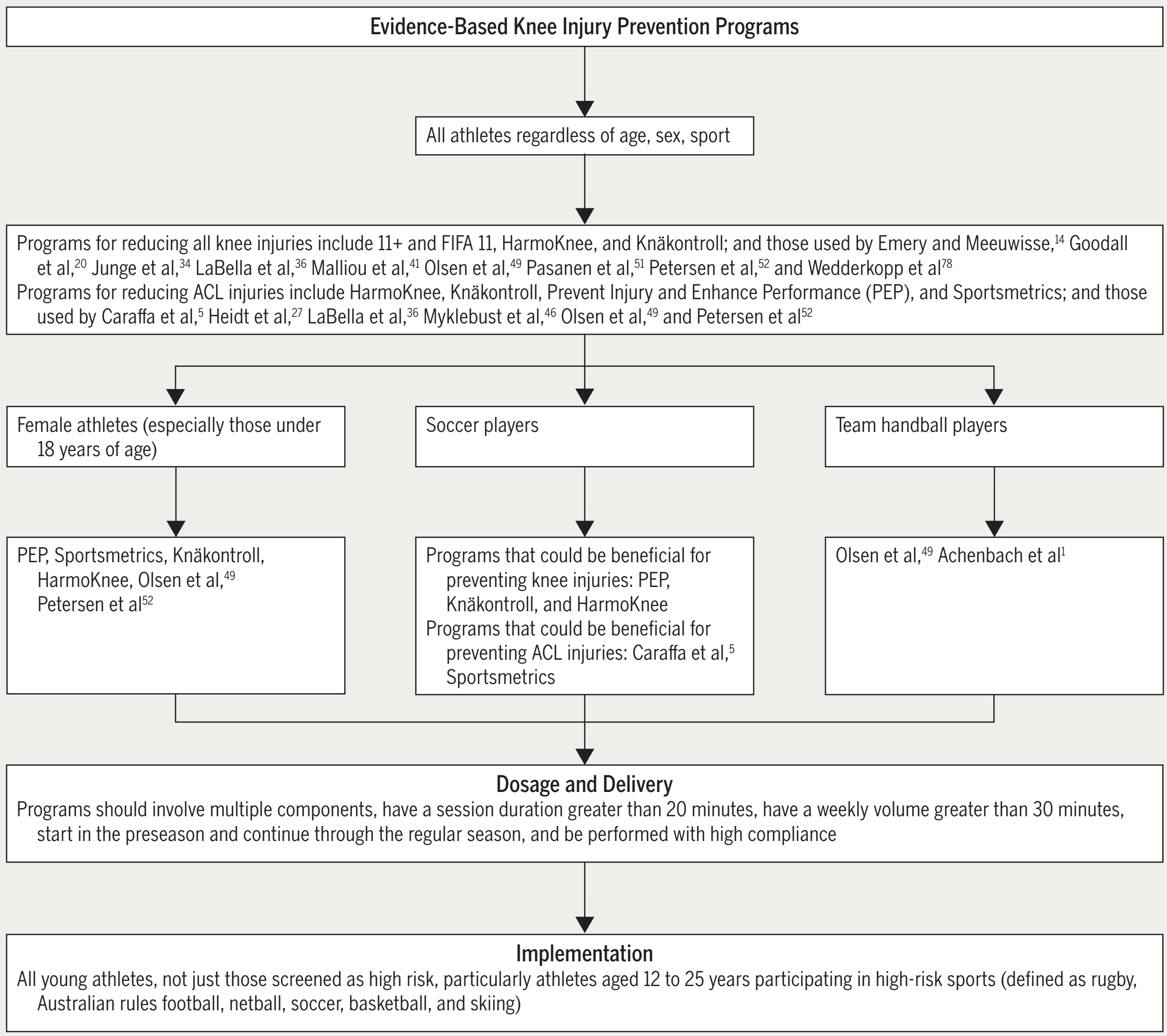

FIGURE 1. Treatment algorithm based on clinical practice guideline findings. The exercise-based knee injury prevention programs heading summarizes the programs observed to be effective when studied across populations. Below the exercise-based knee injury prevention programs heading are the specific populations. These 2 groups (exercise-based knee injury prevention and specific populations) are not mutually exclusive; all programs found in the specific populations area are also found in the exercise-based knee injury prevention area. However, the program listed for specific populations may be more effective or may have been studied in detail in that particular group. The dosage and delivery and implementation sections provide a summary of recommendations on how programs should be set up and executed.

Flexibility (dynamic stretches)
- Quadriceps
- Hamstrings
- Hip adductors
- Hip flexors
- Calf

Running
- Forward running
- Backward running
- Zigzag running, forward and backward
- Bounding

Strength
- Double-leg squat
- Single-leg squat
- Lunges
- Nordic hamstring exercise

Core
- Prone plank
- Bridges

Plyometrics
- Single-leg hopping, anterior/posterior
- "Ice skaters"
- Jump to header or catch ball over head (depending on sport)

FIGURE 2. Exercises included in the 2 videos are available at https://www.jospt.org/doi/suppl/10.2519/jospt.2018.0303.

TABLE 1 Planned Strategies and Tools to Support the Dissemination and Implementation of This Clinical Practice Guideline

Tool	Strategy
"Perspectives for Patients" and videos for clinicians, coaches, and athletes	Patient-oriented guideline summary available on www.jospt.org and www.orthopt.org (**FIGURES 1** and **2**, **TABLE 2**)
Mobile applications of guideline-based exercises for patients/clients, athletes, coaches, and health care practitioners	Marketing and distribution of app using www.orthopt.org
Clinician's quick-reference guide	Summary of guideline recommendations available on www.orthopt.org
Read-for-credit continuing education content	Continuing education content available for physical therapists and athletic trainers from JOSPT
Webinar-based educational offerings for health care practitioners	Guideline-based instruction available for practitioners on www.orthopt.org
Mobile and web-based applications for health care practitioner training	Marketing and distribution of app using www.orthopt.org
Non-English versions of the guidelines and guideline implementation tools	Development and distribution of translated guidelines and tools to JOSPT's international partners and global audience via www.jospt.org

TABLE 2 Contents of Programs Frequently Referenced in the CPG

Area/Study or Program	Equipment Needed	Time for Each Activity	Activities/Muscles Included in Program
Flexibility			
HarmoKnee	None	Muscle activation: approximately 2 minutes of total time, holding position and contracting the muscle for approximately 4 seconds, focusing on "finding" your muscles. Stretching is only recommended in cases of limited range of motion	• Standing calf stretch • Standing quadriceps stretch • Half-kneeling hamstring stretch • Half-kneeling hip flexor stretch • Butterfly adductor stretch • Modified figure-of-four stretch
PEP	None	50 yd each, 30 × 2 repetitions each	• Calf stretch • Quadriceps stretch • Figure-of-four hamstring stretch • Inner thigh stretch • Hip flexor stretch
Sportsmetrics	None	3 sets of 30 seconds each, or 2 laps	• Gastrocnemius • Soleus • Quadriceps • Hamstrings • Hip flexors • Iliotibial band/lower back • Posterior deltoids • Latissimus dorsi • Pectorals/biceps
Running			
HarmoKnee	None	As part of warm-up, 10 minutes total, separate times for each	• Jogging (4-6 minutes) • Backward jogging on toes (1 minute) • High-knee skipping (30 seconds) • Defensive pressure technique: sliding slowly, zigzag backward (30 seconds) • Alternating forward zigzag running and pressure technique: zigzag backward (2 minutes)
KLIP	None	4 phases, each lasting 2 wk. Time/repetitions for each exercise not specified	• Agility: "W" drill • Agility: figure-of-eights • Agility: left/right cuts
Olsen et al[49]	None	30 seconds and 1 repetition each	• Jogging • Backward running with sidesteps • Forward running with knee lifts and heel kicks • Sideways running with crossovers ("carioca") • Sideways running with arms lifted ("parade") • Forward running with trunk rotations • Forward running with intermittent stops • Speed run • Bounding strides • Planting and cutting

Table continues on page A16.

TABLE 2 Contents of Programs Frequently Referenced in the CPG (continued)

Area/Study or Program	Equipment Needed	Time for Each Activity	Activities/Muscles Included in Program
PEP	None	50 yd each, 2 repetitions each	• Jog from line to line of soccer field (cone to cone) • Shuttle run (side to side) • Backward running • Shuttle run with forward/backward running (40 yd) • Diagonal runs (40 yd) • Bounding run (45-50 yd)
Sportsmetrics	None	3 sets of 30 seconds each, or 2 laps	• Skipping • Side shuffle • Cool-down walk (2 minutes)
Balance			
Achenbach et al[1]	Ball optional	Not specified	• Standing on 1 leg with eyes closed, try to destabilize the partner by pressing against their body
Caraffa et al[5]	Rectangular wobble board, round balance board, combined round/rectangular board, BAPS board	2.5 minutes, 4 times a day for each exercise	• Phase 1: single-leg stance, no board • Phase 2: single-leg stance on rectangular board (on 45°) • Phase 3: single-leg stance on round board • Phase 4: single-leg stance on a combined round and rectangular board • Phase 5: single-leg stance on a BAPS board
Myklebust et al[46]	Balance mat, wobble board	Not specified	• Single-leg stance on mat with throw • Standing on mat with partner, try to push partner off • Jump onto mat while catching ball, then turn 180° • Double-leg balance on wobble board with throwing • Double-leg squat on wobble board • Single-leg squat on wobble board • Single-leg stance on wobble board with bounding ball • Two players on wobble boards: try to push the other off
Olsen et al[49]	Balance mat or wobble board	4 minutes and 2 × 90 seconds each	• Passing the ball (2-leg stance) • Squats (1- or 2-leg stance) • Passing the ball (1-leg stance) • Bouncing the ball with eyes closed • Pushing each other off balance
Strength			
Achenbach et al[1]	None	Not specified	• Nordic hamstring eccentric strengthening
Caraffa et al[5]	Step	Not specified (prior to balance training)	• Anterior step-up • Posterior step-up
HarmoKnee	None	1 minute each	• Lunges in place (alternating anterior lunges) • Nordic hamstring eccentric strengthening • Single-leg squat with toe raise
Knäkontroll	Ball	3 sets, 8-15 repetitions. Each exercise with 4 levels of difficulty	• Level 1: double-leg squat • Level 2: double-leg squat with heel raise • Level 3: double-leg squat with ball over head • Level 4: double-leg squat with ball held in front of body • Level 5 (partner exercise): partner stands next to you approximately 1 m away, facing opposite directions; hold ball between you with one hand and the other hand on hip; apply slight pressure on ball while performing knee squat • Level 1: forward walking lunge • Level 2: forward lunge with ball, lateral trunk rotation • Level 3: forward lunge with ball over head • Level 4: lateral lunge • Leve 5 (partner exercise): partner stands in front of you 5-10 m away; perform forward lunge while making throw-in with ball • Level 1: single-leg squat • Level 2: single-leg squat with overhead ball • Level 3: single-leg squat with off leg at differing positions • Level 4: single-leg Romanian deadlift • Level 5 (partner exercise): partner stands slightly oblique in front of you, and ball is pressed between lateral sides of feet of nonsupporting legs
Olsen et al[49]	None	2 minutes and 3 × 10 repetitions each	• Squats to 80° of knee flexion • Nordic hamstring eccentric strengthening

Table continues on page A17.

TABLE 2 Contents of Programs Frequently Referenced in the CPG (continued)

Area/Study or Program	Equipment Needed	Time for Each Activity	Activities/Muscles Included in Program
PEP	None	Varies based on exercise	• Walking lunges, 20 yd × 2 sets • Russian hamstring, 3 sets × 10 repetitions or 30 seconds • Single toe raises, 30 repetitions each side
Sportsmetrics	Weight equipment/ machines	1 set of 12 repetitions for upper body, 1 set of 15 repetitions for trunk and lower body	• Back hyperextension • Leg press • Calf raise • Pullover • Bench press • Latissimus dorsi pull-down • Forearm curl
Core stability			
Achenbach et al[1]	None	Not specified	• Plank • Side plank
HarmoKnee	None	1 minute each	• Sit-ups • Plank on elbows • Bridging
Knäkontroll	None	15-30 seconds	• Level 1: prone plank on knees • Level 2: prone plank on toes • Level 3: prone plank on toes with lateral step • Level 4: side plank • Level 5 (partner exercise): plank with partner holding feet • Level 1: bridge, double leg • Level 2: bridge, single leg • Level 3: bridge, single leg on ball • Level 4: bridge, single leg with hop • Level 5 (partner exercise): partner stands with flexed knees and supports heel of one of your feet in her hands
Sportsmetrics	Weight equipment	1 set of 12 repetitions for upper body, 1 set of 15 repetitions for trunk and lower body	• Abdominal curl
Plyometrics			
Achenbach et al[1]	None	Not specified	• Multidirectional single-leg jumps • "Ice-skater" jumps • Jump run
HarmoKnee	Ball optional	30 seconds each	• Forward and backward double-leg jumps • Lateral single-leg jumps • Forward and backward single-leg jumps • Double-leg jump with or without ball
KLIP	None	4 phases, each lasting 2 wk. Time/repetitions for each exercise not specified	• Straight jumps • Tuck jumps • Standing broad jump • Bound in place • 180° jump • Single-leg lateral leaps • 45° lateral leaps • Combination jumps • Single-leg forward hops • Single-leg 45° lateral hops • Single-leg forward hops × 3
Knäkontroll	None	3 sets, 5-15 repetitions	• Level 1: single-leg forward/backward hops • Level 2: double-leg lateral jumps, landing on single leg • Level 3: take a few quick steps on same spot and make short jump straight forward, landing on 1 foot • Level 4: take a few quick steps on same spot and make short jump, but change direction and jump to 1 side (90° turn); alternate sides • Level 5 (partner exercise): partner stands in front of you approximately 5 m away; make 2-legged jump while heading soccer ball and land on 2 legs
Myklebust et al[46]	None	Not specified	• Run and plant • Double-leg jump forward/backward; partner pushes player (perturbation) • Jump shot (handball) from 30- to 40-cm box with soft landing • Step off 30- to 40-cm box with single-leg landing

Table continues on page A18.

TABLE 2 Contents of Programs Frequently Referenced in the CPG (continued)

Area/Study or Program	Equipment Needed	Time for Each Activity	Activities/Muscles Included in Program
Olsen et al[49]	None	4 minutes and 5 × 30 seconds each	• Jump-shot landings • Forward jumps
PEP	Cones (5-15 cm tall)	20 repetitions or 30 seconds each	• Lateral hops over cone • Forward/backward hops over cone • Single-leg hops over cone • Vertical jumps with headers • Scissors jump
Sportsmetrics	None	Varies based on exercise	• Wall jumps (20 seconds, progressing to 30 seconds) • Tuck jumps (20 seconds, progressing to 30 seconds) • Broad jumps, stick (hold) landing (5-10 repetitions) • Squat jumps (10 seconds, progressing to 25 seconds) • Double-legged cone jumps (30 seconds/30 seconds side to side and back to front) • 180° jumps (20-25 seconds) • Bounding in place (20-25 seconds) • Jump, jump, jump, vertical jump (5-8 repetitions) • Bounding for distance (1-2 runs) • Scissors jump (30 seconds) • Hop, hop, stick landing (5 repetitions per leg) • Step, jump up, down, vertical (5-10 repetitions) • Mattress jumps (30 seconds/30 seconds side to side and back to front) • Single-legged jumps for distance (5 repetitions per leg) • Jump into bounding (3-4 runs)

Abbreviations: BAPS, Biomechanical Ankle Platform System; CPG, clinical practice guideline; KLIP, Knee Ligament Injury Prevention; PEP, Prevent Injury and Enhance Performance.

TABLE 3 Programs Included in This Guideline

Program/Study	Study Type	Participants	Duration	Effect	Harms
Achenbach et al[1]	Block RCT	Intervention, n = 168 Control, n = 111 Male and female team handball players aged 15-17 y	One team handball season	Significant reduction in severe (injuries that caused >28 d of absence from sport) knee injuries Control-group severe knee injury incidence, 0.33/1000 h Intervention-group severe knee injury incidence, 0.04/1000 h Odds ratio = 0.11 (95% CI: 0.01, 0.90; *P* = .02)	None
Caraffa et al[5]	Cohort	n = 600 semi-professional and amateur soccer players in Umbri and Marche, Italy Age and sex not provided	30 days during preseason (20 minutes every day)	Significant difference in injury incidence between intervention and control teams (*P*<.01) Intervention teams, 0.15 ACL injuries per season Control teams, 1.15 ACL injuries per season	None
HarmoKnee					
Kiani et al[35]	Cohort	Intervention, n = 777 Control, n = 729 Female soccer players aged 13-19 y	4 months (approximately 20-25 minutes, twice per week, during preseason, and once per week during the regular season)	Knee injuries: intervention incidence, 0.04/1000 h; control, 0.20/1000 h; unadjusted rate ratio = 0.23 (95% CI: 0.04, 0.83); rate ratio adjusted for compliance = 0.17 (95% CI: 0.04, 0.64) Noncontact knee injuries: intervention, 0.01/1000 h; control, 0.15/1000 h; unadjusted rate ratio = 0.10 (95% CI: 0.00, 0.70); rate ratio adjusted for compliance = 0.06 (95% CI: 0.01, 0.46) There were no ACL injuries in the intervention group	None

Table continues on page A19.

TABLE 3 Programs Included in This Guideline (continued)

Program/Study	Study Type	Participants	Duration	Effect	Harms
KLIP					
Pfeiffer et al[54]	Cohort	Intervention, n = 577 Control, n = 862 Female high school–aged soccer, basketball, or volleyball players	Throughout high school season (20 minutes, but the authors did not report the recommended number of times per week)	Incidence of noncontact ACL injuries in the control group, 0.078/1000 AEs; intervention group, 0.167/1000 AEs Overall, there was a nonsignificant increase in odds of ACL injury in the intervention groups (odds ratio = 2.05; 95% CI: 0.21, 21.7; $P>.05$) There were no noncontact ACL injuries in the volleyball control group and in the soccer and volleyball intervention groups There were more noncontact ACL injuries in the basketball intervention group (0.476/1000 AEs) than in the basketball control group (0.111/1000 AEs)	None
Knäkontroll					
Waldén et al[77]	Stratified RCT	Intervention, n = 2479 Control, n = 2085 Female soccer players aged 13-17 y	Throughout soccer season (15 minutes, twice per week)	64% reduction in ACL injuries in the intervention group (rate ratio = 0.36; 95% CI: 0.15, 0.85; $P = .02$) When adjusted for compliance: 83% reduction in ACL injuries (rate ratio = 0.17; 95% CI: 0.05, 0.57; $P<.01$), 82% reduction in severe knee injury (rate ratio = 0.18; 95% CI: 0.07, 0.45; $P<.01$), 47% reduction in all acute knee injuries (rate ratio = 0.53; 95% CI: 0.30, 0.94; $P = .03$)	None
Myklebust et al[46]	Cohort	Control season, n = 942 First intervention season, n = 855 Second intervention season, n = 850 Female Norwegian team handball league players; mean age not provided	Throughout team handball season, including preseason (15 minutes, 3 times per week during preseason and once per week during regular season)	Control-season ACL injury incidence, 0.14/1000 playing hours First-intervention-season ACL injury incidence, 0.13/1000 playing hours Second-intervention-season ACL injury incidence, 0.06/1000 playing hours No significant difference in injury rate (odds ratio = 0.52; 95% CI: 0.15, 1.82; $P = .31$) When adjusted for compliance, there was a significant decrease in injury risk in the elite division (odds ratio = 0.06; 95% CI: 0.01, 0.54; $P = .01$)	None
Olsen et al[49]	Cluster RCT	Intervention, n = 958 Control, n = 879 Female team handball players aged 16-17 y	Through one 8-month team handball season (15-20 minutes, 15 consecutive training sessions at the start of the season, followed by once per week for the remainder of the season)	Significant reduction in all injuries (relative risk = 0.49; 95% CI: 0.39, 0.63; $P<.01$) Acute knee injuries: relative risk = 0.45; 95% CI: 0.25, 0.81; $P<.01$ Number of athletes needed to treat to prevent 1 acute knee injury was 43 Significant reduction in knee ligament injuries (relative risk = 0.20; 95% CI: 0.06, 0.70; $P = .01$) Nonsignificant reduction in meniscal injuries (relative risk = 0.27; 95% CI: 0.06, 1.28; $P = .10$)	None
PEP					
Gilchrist et al[19]	Cluster RCT	Control, n = 852 Intervention, n = 583 NCAA Division I female soccer players; mean age, 19.9 y	12 weeks through collegiate soccer season (15-20 minutes, 3 times per week)	Overall, no significant difference in injury rates for all knee injuries ($P = .86$) or ACL injuries ($P = .20$) The intervention group had a lower ACL injury rate in practices ($P = .01$), a lower late-season ACL injury rate ($P = .03$), a lower rate of noncontact ACL injuries in those who reported a history of ACL injury ($P = .05$), and there was no difference between groups in the injury rates during games ($P = .62$), early in the season ($P = .93$), or among those with no history of prior ACL injury ($P = .43$)	One player tripped during the lateral hops and had a tibial and fibular fracture, after which the cone height used was adjusted to be shorter

Table continues on page A20.

TABLE 3 Programs Included in This Guideline (continued)

Program/Study	Study Type	Participants	Duration	Effect	Harms
Mandelbaum et al[42]	Cohort	Year 1: intervention, n = 1041; control, n = 1905 Year 2: intervention, n = 844; control, n = 1931 Female soccer players aged 14-18 y	Throughout soccer season (20 minutes, but the authors did not report recommended number of times per week)	Overall incidence of ACL injuries for the intervention group was 0.09/1000 AEs, and for the control group was 0.49/1000 AEs, over the 2-y study Rate ratio = 0.18, *P*<.01 When broken down by year: year 1, 89% reduction in ACL injuries (rate ratio = 0.11, *P*<.01); year 2, 74% reduction in risk (relative risk = 0.26, *P*<.01)	None
Sportsmetrics					
Hewett et al[29]	Cohort	Female intervention, n = 366 Female control, n = 463 Male control, n = 434 High school–aged soccer, basketball, and volleyball players	6 weeks during preseason (60-90 minutes, 3 times per week)	Trained females had a significantly lower rate of severe knee injuries (incidence, 0.12/1000 AEs) than untrained females (incidence, 0.43/1000 AEs; *P* = .05) Untrained females had a higher rate of severe knee injuries than males (incidence, 0.09/1000 AEs; *P* = .03), but there was no difference in rate of severe knee injuries between trained females and males (*P* = .86) The trained female group (incidence, 0) had a significantly lower rate of noncontact knee injuries compared to the untrained female (incidence, 0.35/1000 AEs; *P* = .01) and untrained male groups (incidence, 0.05/1000 AEs; *P* = .01)	Not reported

Abbreviations: ACL, anterior cruciate ligament; AE, athlete-exposure; CI, confidence interval; CPG, clinical practice guideline; KLIP, Knee Ligament Injury Prevention; NCAA, National Collegiate Athletic Association; PEP, Prevent Injury and Enhance Performance; RCT, randomized controlled trial.

TABLE 4 Links to Studies Included in the Meta-analyses and Systematic Reviews That Met the CPG Inclusion Criteria

Program	Link
Achenbach et al[1]	https://www.ncbi.nlm.nih.gov/pubmed/29058022 https://doi.org/10.1007/s00167-017-4758-5
Caraffa et al[5]	http://www.ncbi.nlm.nih.gov/pubmed/8963746 https://link.springer.com/content/pdf/10.1007/BF01565992.pdf
HarmoKnee	http://harmoknee.com/ http://www.ncbi.nlm.nih.gov/pubmed/20065198 http://archinte.jamanetwork.com/article.aspx?articleid=481521
KLIP	http://www.ncbi.nlm.nih.gov/pubmed/15574070 https://journals.lww.com/jbjsjournal/Abstract/2006/08000/Lack_of_Effect_of_a_Knee_Ligament_Injury.12.aspx
Knäkontroll	App available on Apple or Android platforms: https://itunes.apple.com/se/app/knakontroll/id573826071?mt=8 https://play.google.com/store/apps/details?id=se.rf.sisu&hl=en https://www.ncbi.nlm.nih.gov/pubmed/22556050 http://www.bmj.com/content/344/bmj.e3042.full.pdf+html
Myklebust et al[46]	http://www.ncbi.nlm.nih.gov/pubmed/12629423 https://onlinelibrary.wiley.com/doi/pdf/10.1034/j.1600-0838.2003.00341.x
Olsen et al[49]	http://www.ncbi.nlm.nih.gov/pubmed/12629423 https://onlinelibrary.wiley.com/doi/pdf/10.1034/j.1600-0838.2003.00341.x
PEP	https://www.youtube.com/watch?v=t_yz7yWLo5o http://la84.org/a-practical-guide-to-the-pep-program/ https://www.ncbi.nlm.nih.gov/pubmed/15888716 http://ajs.sagepub.com/content/36/8/1476.full.pdf+html http://ajs.sagepub.com/content/33/7/1003.full.pdf+html
Sportsmetrics	http://sportsmetrics.org/ https://www.ncbi.nlm.nih.gov/pubmed/10569353 http://ajs.sagepub.com/content/27/6/699.full.pdf+html

Table continues on page A21.

TABLE 4 Links to Studies Included in the Meta-analyses and Systematic Reviews That Met the CPG Inclusion Criteria (continued)

Program	Link
11+*	http://fifamedicinediploma.com/lessons/prevention-fifa-11/ http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3867089/
Emery and Meeuwisse[14]*	https://www.ncbi.nlm.nih.gov/pubmed/20547668 http://bjsm.bmj.com/content/44/8/555.abstract
Goodall et al[20]*	https://www.ncbi.nlm.nih.gov/pubmed/22924758 http://dx.doi.org/10.1080/17457300.2012.717085
Heidt et al[27]*	https://www.ncbi.nlm.nih.gov/pubmed/11032220 http://ajs.sagepub.com/content/28/5/659.abstract
Junge et al[34]*	https://www.ncbi.nlm.nih.gov/pubmed/12238997 http://ajs.sagepub.com/content/30/5/652.abstract
LaBella et al[37]*	https://www.ncbi.nlm.nih.gov/pubmed/18832542 http://cpj.sagepub.com/content/48/3/327.long
Malliou et al[41]*	https://www.ncbi.nlm.nih.gov/pubmed/15446640 http://journals.sagepub.com/doi/abs/10.2466/pms.99.1.149-154
Pasanen et al[51]*	https://www.ncbi.nlm.nih.gov/pubmed/18595903 http://www.bmj.com/content/337/bmj.a295
Petersen et al[52]*	https://www.ncbi.nlm.nih.gov/pubmed/23189409
Söderman et al[60]*	https://www.ncbi.nlm.nih.gov/pubmed/11147154 https://link.springer.com/article/10.1007%2Fs001670000147
Wedderkopp et al[78]*	https://www.ncbi.nlm.nih.gov/pubmed/9974196 https://onlinelibrary-wiley-com.e.bibl.liu.se/doi/pdf/10.1111/j.1600-0838.1999.tb00205.x

Abbreviations: CPG, clinical practice guideline; KLIP, Knee Ligament Injury Prevention; PEP, Prevent Injury and Enhance Performance.
**The individual studies of these programs did not meet the CPG inclusion criteria.*

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APPENDIX A

SEARCH STRATEGY FOR ALL DATABASES SEARCHED

PubMed

Search Strategy	Search Limits
(Sports [MeSH] OR Athletes [MeSH] OR Exercise [MeSH] OR Athletic Injuries [MeSH]) AND ((Knee Injuries [MeSH]) OR ((Wounds and Injuries [MeSH] OR injur* [TW]) AND (ACL [TW] OR Anterior Cruciate Ligament* [TW] OR Anterior Cruciate Ligament [MeSH]))) AND (Risk Reduction Behavior [MeSH] OR Prevent* [TW] OR Predict* [TW])	English only, then Clinical Trial, Clinical Trial Phase I, Clinical Trial Phase II, Clinical Trial Phase III, Clinical Trial Phase IV, Comparative Study, Controlled Clinical Trial, Evaluation Studies, Guideline, Introductory Journal Article, Journal Article, Meta-Analysis, Multicenter Study, Observational Study, Practice Guideline, Pragmatic Clinical Trial, Randomized Control Trial, Systematic Reviews, Twin Study

Scopus

Search Strategy	Search Limits
(TITLE-ABS-KEY (Sport*) OR TITLE-ABS-KEY (Athlet*) OR TITLE-ABS-KEY (Exercise) OR TITLE-ABS-KEY (Athletic Injur*)) AND ((TITLE-ABS-KEY (Knee Injur*)) OR ((TITLE-ABS-KEY(Wound*) OR TITLE-ABS-KEY (Injur*)) AND (TITLE-ABS-KEY (Anterior Cruciate Ligament) OR TITLE-ABS-KEY (ACL)))) AND (TITLE-ABS-KEY (Risk Reduction) OR TITLE-ABS-KEY (Prevent*) OR TITLE-ABS-KEY (Predict*))	English only, limit to Article, Review, and Article in Press

SPORTDiscus

Search Strategy	Search Limits
((TI (Sport*) OR AB (Sport*) OR (DE "Sports")) OR (TI (Athlet*) OR AB (Athlet*) OR (DE "ATHLETICS")) OR (TI (Exercise) OR AB (Exercise) OR (DE "EXERCISE")) OR (TI (Athletic Injur*) OR AB (Athletic Injur*))) AND ((TI (Knee Injur*) OR AB (Knee Injur*)) OR ((((TI (Wound*) OR AB (Wound*)) OR (TI (Injur*) OR AB (Injur*))) OR (DE "WOUNDS & injuries")) AND ((TI (Anterior Cruciate Ligament) OR AB (Anterior Cruciate Ligament) OR (DE "ANTERIOR cruciate ligament")) OR (TI (ACL) OR AB (ACL))))) AND ((TI (Risk Reduction) OR AB (Risk Reduction)) OR (TI (Prevent*) OR AB (Prevent*) OR (DE "PREVENTION")) OR (TI (Predict*) OR AB (Predict*)))	English, English Abstract Only, Peer-Reviewed, Academic Journal

CINAHL

Search Strategy	Search Limits
((TI (Sport*) OR AB (Sport*) OR (MH "Sports+")) OR (TI (Athlet*) OR AB (Athlet*)) OR (TI (Exercise) OR AB (Exercise) OR (MH "Exercise+")) OR (TI (Athletic Injur*) OR AB (Athletic Injur*) OR (MH "Athletic Injuries+"))) AND ((TI (Knee Injur*) OR AB (Knee Injur*) OR (MH "Knee Injuries+")) OR ((TI (Wound*) OR AB (Wound*) OR TI (Injur*) OR AB (Injur*) OR (MH "Wounds and Injuries+")) AND (TI (Anterior Cruciate Ligament) OR AB (Anterior Cruciate Ligament) OR TI (ACL) OR AB (ACL) OR (MH "Anterior Cruciate Ligament+")))) AND ((TI (Risk Reduction) OR AB (Risk Reduction)) OR (TI (Prevent*) OR AB (Prevent*)) OR (TI (Predict*) OR AB (Predict*)))	English Language checkbox, Adolescent, Adult, Middle-Aged, Aged 65+. Aged 80+, Clinical Trial, Corrected Article, Journal Article, Practice Guidelines, Research, Systematic Review

Cochrane

Search Strategy	Search Limits
((Sport*) OR (Athlet*) OR (Exercise) OR (Athletic Injur*)) AND (((Knee Injur*)) OR (((Wound*) OR (Injur*)) AND ((Anterior Cruciate Ligament) OR (ACL)))) AND ((Risk Reduction) OR (Prevent*) OR (Predict*))	Cochrane Reviews - ALL, Other Reviews, Trials, Technology Assessments, Economic Evaluations

APPENDIX B

SEARCH DATES AND RESULTS

Initial Search

Database	Date Conducted	Results, n
PubMed	3/31/2015	812
Scopus	3/31/2015	2083
SPORTDiscus	3/31/2015	511
CINAHL	3/31/2015	275
Cochrane Library	3/31/2015	145
Cochrane reviews		6
Other reviews		12
Trials		126
Technology assessments		0
Economic evaluations		1
Total		3826
Total with duplicates removed		2623

Search Update (2016)

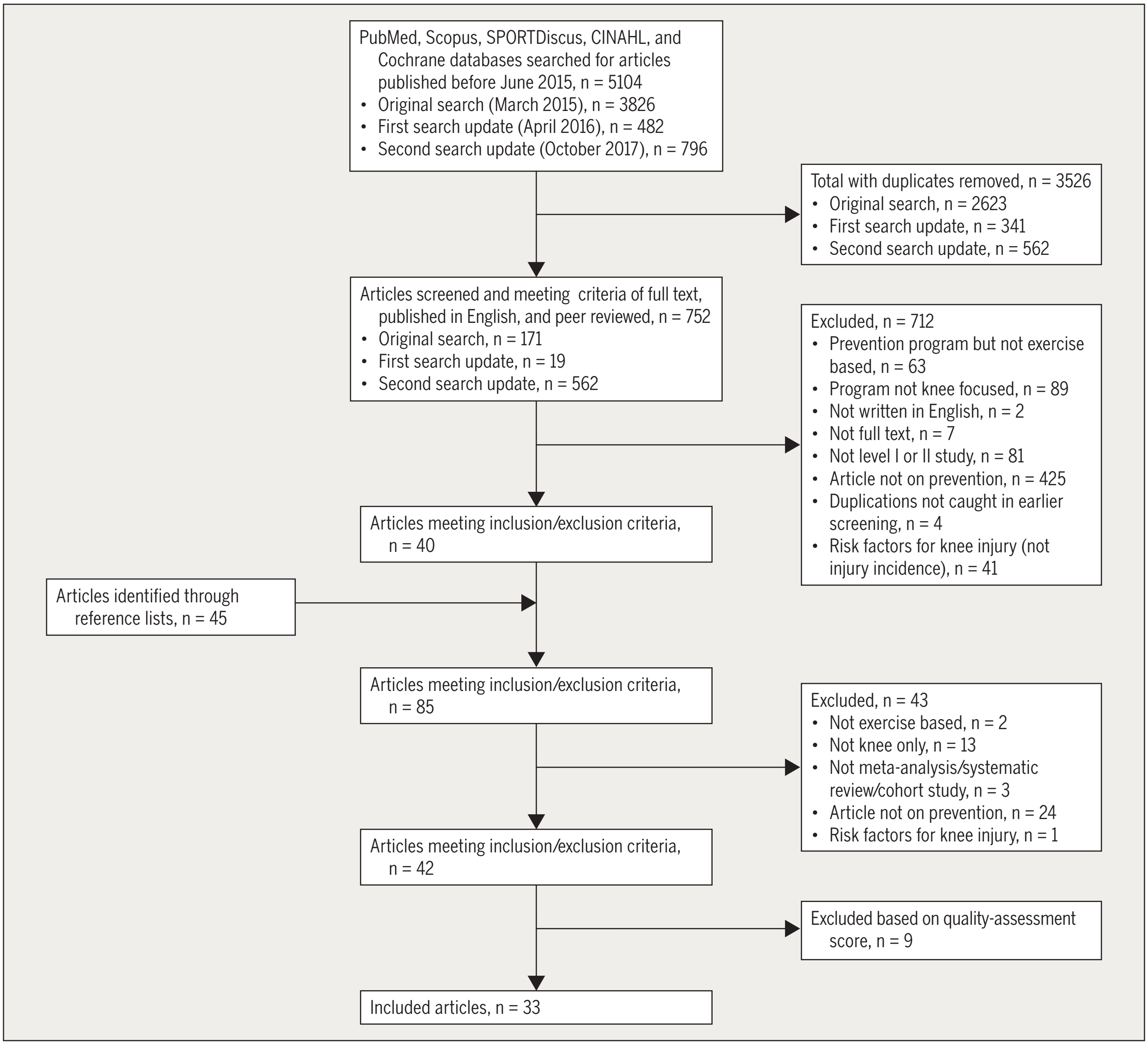
Database	Date Conducted	Results, n
PubMed	4/1/2016	57
Scopus	4/1/2016	297
SPORTDiscus	4/1/2016	96
CINAHL	4/1/2016	18
Cochrane Library	4/1/2016	14
Cochrane reviews		2
Other reviews		0
Trials		12
Technology assessments		0
Economic evaluations		0
Total		482
Total with duplicates removed		341

Search Update (2017)

Database	Date Conducted	Results, n
PubMed	10/19/2017	129
Scopus	10/19/2017	508
SPORTDiscus	10/19/2017	94
CINAHL	10/19/2017	21
Cochrane Library	10/19/2017	44
Cochrane reviews		1
Other reviews		0
Trials		43
Technology assessments		0
Economic evaluations		0
Total		796
Total with duplicates removed		562

APPENDIX C

FLOW CHART OF LITERATURE REVIEW PROCESS



APPENDIX D

INCLUDED ARTICLES

Achenbach L, Krutsch V, Weber J, et al. Neuromuscular exercises prevent severe knee injury in adolescent team handball players. *Knee Surg Sports Traumatol Arthrosc*. 2018;26:1901-1908. https://doi.org/10.1007/s00167-017-4758-5

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APPENDIX D

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APPENDIX E

QUALITY-ASSESSMENT SCORES

Systematic Reviews and Meta-analyses: AMSTAR Checklist*

Study	1	2	3	4	5	6	7	8	9	10	11	Quality†
Alentorn-Geli et al[2]	x	x	x			x	x					5
Chang and Lai[6]	x	x					x				x	4
Donnell-Fink et al[9]	x	x	x			x	x		x	x	x	8
Gagnier et al[18]	x	x	x			x	x	x	x	x	x	9
Grimm et al[22]	x	x	x			x	x		x	x	x	8
Grimm et al[23]	x	x	x			x	x			x	x	7
Grindstaff et al[24]	x	x	x			x	x	x		x		7
Hewett and Myer[30]	x		x									2
Hewett et al[28]	x					x					x	3
Michaelidis and Koumantakis[43]	x		x			x	x				x	5
Myer et al[45]	x			x		x	x			x	x	6
Noyes and Barber-Westin[48]	x		x			x					x	4
Noyes and Barber Westin[47]	x		x									2
Padua and Marshall[50]	x						x	x				3
Pfile and Curioz[55]	x	x	x	x		x	x	x				7
Sadoghi et al[57]	x		x		x		x		x	x	x	7
Stevenson et al[64]	x	x	x			x	x				x	6
Stojanovic and Ostojic[65]	x						x	x			x	4
Sugimoto et al[68]	x	x	x	x		x	x		x	x	x	9
Sugimoto et al[69]	x		x	x	x	x	x	x				7
Sugimoto et al[66]	x			x		x	x	x	x	x	x	8
Sugimoto et al[67]	x	x				x	x	x	x	x	x	8
Sugimoto et al[70]	x	x	x	x		x	x	x		x	x	9
Taylor et al[72]	x	x	x			x	x		x	x	x	8
Yoo et al[80]	x		x			x			x	x		5

Abbreviation: AMSTAR, A Measurement Tool to Assess Systematic Reviews.
**Yes/no. Items: 1, Was an a priori design provided? 2, Was there duplicate study selection and data extraction? 3, Was a comprehensive literature search performed? 4, Was the status of publication (ie, gray literature) used as an inclusion criterion? 5, Was a list of studies (included and excluded) provided? 6, Were the characteristics of the included studies provided? 7, Was the scientific quality of the included studies assessed and documented? 8, Was the scientific quality of the included studies used appropriately in formulating conclusions? 9, Were the methods used to combine the findings of studies appropriate? 10, Was the likelihood of publication bias assessed? 11, Was the conflict of interest included?*
†What is your overall assessment of the methodological quality of this review? High quality, 8 or greater; acceptable, 5, 6, or 7; reject, 4 or less.

APPENDIX E

Randomized Controlled Trials: Physiotherapy Evidence Database Scale (PEDro)*

Study	1	2	3	4	5	6	7	8	9	10	11	Quality†
Achenbach et al[1]		x		x				x	x	x	x	6
Gilchrist et al[19]	x	x		x			x	x	x	x	x	8
Hägglund et al[26]	x							x	x	x	x	5
Olsen et a[49]	x	x	x	x			x	x		x	x	8
van Beijsterveldt et al[73]	x	x	x	x				x	x	x	x	8
Vescovi and VanHeest[76]	x	x								x	x	4
Waldén et al[77]	x	x	x	x			x		x	x	x	8

**Items:* 1, Eligibility criteria were specified; 2, Subjects were randomly allocated to groups (in a crossover study, subjects were randomly allocated an order in which treatments were received); 3, Allocation was concealed; 4, The groups were similar at baseline regarding the most important prognostic indicators; 5, There was blinding of all subjects; 6, There was blinding of all therapists who administered the therapy; 7, There was blinding of all assessors who measured at least 1 key outcome; 8, Measures of at least 1 key outcome were obtained from more than 85% of the subjects initially allocated to groups; 9, All subjects for whom outcome measures were available received the treatment or control condition as allocated, or, where this was not the case, data for at least 1 key outcome were analyzed by "intention to treat"; 10, The results of between-group statistical comparisons were reported for at least 1 key outcome; 11, The study provides both point measures and measures of variability for at least 1 key outcome.*

†Quality rating: 8 or higher, high; 5, 6, or 7, acceptable; 4 or less, reject.

Cohort Studies: Scottish Intercollegiate Guidelines Network Checklist (SIGN)*

Study	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Quality†
Caraffa et al[5]	x	x	x	x		x	x		x	x	x				9
Hewett et al[29]		x			x		x		x	x					5
Kiani et al[35]	x	x	x		x	x	x			x	x	x	x	x	11
LaBella et al[37]	x	x					x		x						4
Mandelbaum et al[42]	x	x	x				x		x	x		x		x	8
Myer et al[44]	x						x			x	x	x			5
Myklebust et al[46]	x	x	x		x							x	x	x	7
Pfeiffer et al[54]	x					x	x		x			x	x		6

**Items: 1, The study addresses an appropriate and clearly focused question; 2, The 2 groups being studied are selected from source populations that are comparable in all respects other than the factor under investigation; 3, The study indicates how many of the people asked to take part did so, in each of the groups being studied; 4, The likelihood that some eligible subjects might have the outcome at the time of enrollment is assessed and taken into account in the analysis; 5, What percentage of individuals or clusters recruited into each arm of the study dropped out before the study was completed? 6, Comparison is made between full participants and those lost to follow-up, by exposure status; 7, The outcomes are clearly defined; 8, The assessment of outcome is made blind to exposure status (if the study is retrospective, this may not be applicable); 9, Where blinding was not possible, there is some recognition that knowledge of exposure status could have influenced the assessment of outcome; 10, The method of assessment of exposure is reliable; 11, Evidence from other sources is used to demonstrate that the method of outcome assessment is valid and reliable; 12, Exposure level or prognostic factor is assessed more than once; 13, The main potential confounders are identified and taken into account in the design and analysis; 14, Have confidence intervals been provided?*

†How well was the study done to minimize the risk of bias or confounding? Quality rating: 8 or higher, high; 5, 6, or 7, acceptable; 4 or less, reject.

Economic Analysis: Drummond Checklist*[11]

Question/Checklist Item	Swart et al[71]	Lewis et al[38]
Was a well-defined question posed in answerable form?		
Did the study examine both costs and effects of the service(s) or program(s)?	x	x
Did the study involve a comparison of alternatives?	x	x
Was a viewpoint for the analysis stated and was the study placed in any particular decision-making context?	x	x
Was a comprehensive description of the competing alternatives given?		
Were any relevant alternatives omitted?	x	
Was (should) a do-nothing alternative (be) considered?	x	
Was the effectiveness of the program or services established?		
Was this done through a randomized, controlled clinical trial? If so, did the trial protocol reflect what would happen in regular practice?		

Table continues on page A33.

APPENDIX E

Question/Checklist Item	Swart et al[71]	Lewis et al[38]
Were effectiveness data collected and summarized through a systematic overview of clinical studies? If so, were the search strategies and rules for inclusion or exclusion outlined?	x	
Were observational data or assumptions used to establish effectiveness? If so, what are the potential biases in results?	x	x
Were all the important and relevant costs and consequences for each alternative identified?		
Was the range wide enough for the research question at hand?	x	x
Did it cover all relevant viewpoints?	x	x
Were the capital costs, as well as operating costs, included?	x	x
Were costs and consequences measured accurately in appropriate physical units?		
Were the sources of resource utilization described and justified?	x	x
Were any of the identified items omitted from measurement? If so, does this mean that they carried no weight in the subsequent analysis?		
Were there any special circumstances that made measurement difficult? Were these circumstances handled appropriately?		
Were costs and consequences valued credibly?		
Were the sources of all values clearly identified?	x	x
Were market values employed for changes involving resources gained or depleted?		x
Where market values were absent, or market values did not reflect actual values, were adjustments made to approximate market values?	x	
Was the valuation of consequences appropriate for the question posed?	x	x
Were costs and consequences adjusted for differential timing?		
Were costs and consequences that occur in the future "discounted" to their present values?		x
Was any justification given for the discounted rate used?		x
Was an incremental analysis of costs and consequences of alternatives performed?		
Were the additional costs generated by one alternative over another compared to the additional effects, benefits, or utilities generated?		x
Was allowance made for uncertainty in the estimates of cost and consequences?		
If patient-level data on costs or consequences were available, were appropriate statistical analyses performed?	x	x
If a sensitivity analysis was employed, was justification provided for the ranges or distributions of values, and the form of sensitivity analysis used?	x	x
Were the conclusions of the study sensitive to the uncertainty in the results, as quantified by the statistical and/or sensitivity analysis?	x	x
Did the presentation and discussion of study results include all issues of concern to users?		
Were the conclusions of the analysis based on some overall index or ratio of costs to consequences? If so, was the index interpreted intelligently or in a mechanistic fashion?	x	x
Were the results compared with those of others who have investigated the same question? If so, were allowances made for potential differences in study methodology?		
Did the study discuss the generalizability of the results to other settings and patient/client groups?	x	
Did the study allude to, or take account of, other important factors in the choice or decision under consideration?	x	x
Did the study discuss issues of implementation, such as feasibility of adopting the "preferred" program given existing financial or other constraints, and whether any freed resources could be redeployed to other worthwhile programs?	x	x
Quality score	21	20

**Only studies that met inclusion/exclusion criteria were reviewed for quality. There are studies referred to in this clinical practice guideline that did not meet the inclusion/exclusion criteria themselves but receive mention because they are included in systematic reviews or meta-analyses that did meet the inclusion/exclusion criteria, for example, Söderman et al.[60]*

APPENDIX F

LEVELS OF EVIDENCE TABLE*

Level	Intervention/ Prevention	Pathoanatomic/Risk/ Clinical Course/ Prognosis/Differential Diagnosis	Diagnosis/Diagnostic Accuracy	Prevalence of Condition/Disorder	Exam/Outcomes
I	Systematic review of high-quality RCTs High-quality RCT†	Systematic review of prospective cohort studies High-quality prospective cohort study‡	Systematic review of high-quality diagnostic studies High-quality diagnostic study§ with validation	Systematic review, high-quality cross-sectional studies High-quality cross-sectional study‖	Systematic review of prospective cohort studies High-quality prospective cohort study
II	Systematic review of high-quality cohort studies High-quality cohort study‡ Outcomes study or ecological study Lower-quality RCT¶	Systematic review of retrospective cohort study Lower-quality prospective cohort study High-quality retrospective cohort study Consecutive cohort Outcomes study or ecological study	Systematic review of exploratory diagnostic studies or consecutive cohort studies High-quality exploratory diagnostic studies Consecutive retrospective cohort	Systematic review of studies that allows relevant estimate Lower-quality cross-sectional study	Systematic review of lower-quality prospective cohort studies Lower-quality prospective cohort study
III	Systematic reviews of case-control studies High-quality case-control study Lower-quality cohort study	Lower-quality retrospective cohort study High-quality cross-sectional study Case-control study	Lower-quality exploratory diagnostic studies Nonconsecutive retrospective cohort	Local nonrandom study	High-quality cross-sectional study
IV	Case series	Case series	Case-control study	...	Lower-quality cross-sectional study
V	Expert opinion	Expert opinion	Expert opinion	Expert opinion	Expert opinion

Abbreviation: RCT, randomized clinical trial.
Adapted from Phillips et al[56] (http://www.cebm.net/index.aspx?o=1025). See also **APPENDIX G.**
†*High quality includes RCTs with greater than 80% follow-up, blinding, and appropriate randomization procedures.*
‡*High-quality cohort study includes greater than 80% follow-up.*
§*High-quality diagnostic study includes consistently applied reference standard and blinding.*
‖*High-quality prevalence study is a cross-sectional study that uses a local and current random sample or censuses.*
¶*Weaker diagnostic criteria and reference standards, improper randomization, no blinding, and less than 80% follow-up may add bias and threats to validity.*

APPENDIX G

PROCEDURES USED FOR ASSIGNING LEVELS OF EVIDENCE

- Level of evidence is assigned based on the study design using the Levels of Evidence table (**APPENDIX F**), assuming high quality (eg, for intervention, randomized clinical trial starts at level I)
- Study quality is assessed using the critical appraisal tool, and the study is assigned 1 of 4 overall quality ratings based on the critical appraisal results
- Level of evidence assignment is adjusted based on the overall quality rating:
  - High quality (high confidence in the estimate/results): study remains at assigned level of evidence (eg, if the randomized clinical trial is rated high quality, its final assignment is level I). High quality should include:
    - Randomized clinical trial with greater than 80% follow-up, blinding, and appropriate randomization procedures
    - Cohort study includes greater than 80% follow-up
    - Diagnostic study includes consistently applied reference standard and blinding
    - Prevalence study is a cross-sectional study that uses a local and current random sample or censuses
  - Acceptable quality (the study does not meet requirements for high quality and weaknesses limit the confidence in the accuracy of the estimate): downgrade 1 level
    - Based on critical appraisal results
  - Low quality: the study has significant limitations that substantially limit confidence in the estimate: downgrade 2 levels
    - Based on critical appraisal results
  - Unacceptable quality: serious limitations—exclude from consideration in the guideline
    - Based on critical appraisal results

APPENDIX H

EFFICACY OF EXERCISE-BASED KNEE INJURY PREVENTION PROGRAMS

Review/Included Articles	Outcomes Examined	Findings
Donnell-Fink et al[9]		
Caraffa et al,[5] Emery and Meeuwisse,[14] Gilchrist et al,[19] Goodall et al,[20] Grooms et al,[25] Heidt et al,[27] Hewett et al,[29] Junge et al,[34] Kiani et al,[35] LaBella et al,[37] Longo et al,[40] Malliou et al,[41] Mandelbaum et al,[42] Myklebust et al,[46] Olsen et al,[49] Pasanen et al,[51] Petersen et al,[52] Pfeiffer et al,[54] Söderman et al,[60] Soligard et al,[62] Steffen et al,[63] van Beijsterveldt et al,[74] Waldén et al,[77] Wedderkopp et al[78]	Primary: incidence of knee and ACL injuries Secondary: subgroup analysis of knee and ACL injuries Tertiary: incidence of noncontact ACL injuries	Primary: pooled incidence reduction ratio for knee injury prevention = 0.731 (95% CI: 0.61, 0.87), pooled incidence reduction ratio for ACL injury prevention = 0.493 (95% CI: 0.285, 0.854) Secondary subgroup analysis: age (dichotomized by high school aged or older than high school aged) not associated with knee or ACL injury reduction, knee injuries (high school incidence reduction ratio = 0.79, older than high school incidence reduction ratio = 0.58; *P* = .20), ACL injuries (high school incidence reduction ratio = 0.36, older than high school incidence reduction ratio = 0.58; *P* = .41) Programs during preseason or preseason plus in-season versus in-season-only programs Lower risk of knee injury in preseason/preseason plus in-season (incidence reduction ratio = 0.24) than in-season only (incidence reduction ratio = 0.75, *P*<.01), no difference for ACL injuries (preseason/preseason-plus-in-season incidence reduction ratio = 0.32, in-season-only incidence reduction ratio = 0.57; *P* = .33) Tertiary: pooled incidence rate ratio for noncontact ACL injuries = 0.51 (95% CI: 0.30, 0.88)
Gagnier et al[18]		
Caraffa et al,[5] Ettlinger et al,[16] Gilchrist et al,[19] Heidt et al,[27] Hewett et al,[29] Kiani et al,[35] Mandelbaum et al,[42] Myklebust et al,[46] Olsen et al,[49] Pasanen et al,[51] Petersen et al,[52] Pfeiffer et al,[54] Söderman et al,[60] Steffen et al[63]	Primary: overall ACL injury incidence Secondary: subgroup analysis of ACL injury incidence	Primary: pooled incidence rate ratio = 0.49 (95% CI: 0.30, 0.79; *P*<.01), with some effects of heterogeneity Secondary subgroup analysis: pooled incidence rate ratio smaller (stronger inverse association) for nonrandomized cohort studies (pooled incidence rate ratio = 0.38; 95% CI: 0.20, 0.70; *P*<.01), studies in the United States (pooled incidence rate ratio = 0.36; 95% CI: 0.15, 0.88; *P* = .03), studies of longer duration (>14 mo) (pooled incidence rate ratio = 0.41; 95% CI: 0.20, 0.84; *P* = .01), studies with more hours of training per week (>0.75 h) (pooled incidence rate ratio = 0.38; 95% CI: 0.18, 0.77; *P*<.01), studies that reported better compliance (>64%) (pooled incidence rate ratio = 0.39; 95% CI: 0.17, 0.89; *P* = .03), studies that reported no dropouts (pooled incidence rate ratio = 0.30; 95% CI: 0.15, 0.62; *P*<.01), and studies that included only soccer players (pooled incidence rate ratio = 0.30; 95% CI: 0.16, 0.56; *P*<.01). Little difference, though significant, for females (pooled incidence rate ratio = 0.51; 95% CI: 0.28, 0.94; *P* = .03). No significant difference between those interventions that included plyometric exercises compared to those that did not (no *P* value presented)
Sadoghi et al[57]		
Caraffa et al,[5] Gilchrist et al,[19] Heidt et al,[27] Hewett et al,[29] Mandelbaum et al,[42] Petersen et al,[52] Petersen et al,[53] Pfeiffer et al,[54] Söderman et al,[60] Myklebust et al[46]	Risk of ACL injury	Risk differences reported in the component studies varied considerably Numbers needed to treat ranged from 5 to 187 One study had a lower risk in controls Pooled risk ratio was 0.38 (95% CI: 0.20, 0.72; *P*<.01), indicating a significant decrease in risk in the intervention groups Stratified by sex: pooled risk ratio for women = 0.48 (95% CI: 0.26, 0.89; *P* = .02) and for men = 0.15 (95% CI: 0.08, 0.28; *P*<.01) Use of a balance board or video assistance, the duration of follow-up, or year of publication did not affect the pooled risk ratio Conducting the intervention during the preseason, compared to during the playing season, reduced the risk by 19.1%, but this was not significant

Abbreviations: ACL, anterior cruciate ligament; CI, confidence interval.

APPENDIX I

EFFICACY OF EXERCISE-BASED KNEE INJURY PREVENTION PROGRAMS IN MALE AND FEMALE PARTICIPANTS

Sex/Review/Included Articles	Outcomes Examined	Findings
Male		
Alentorn-Geli et al[2]		
Bencke et al,[3] Caraffa et al,[5] Cochrane et al,[7] Dempsey et al,[8] Donnelly et al,[10] Grooms et al,[25] Jamison et al[33]	Reduction of ACL injury	Two of 7 studies examined the effect of interventions on ACL injury rates: 1 found a significant reduction in ACL injury rates,[5] 1 had no ACL injuries in either group (but did have a 72% decrease in lower extremity injury risk)[25] The quality of studies increased over time
Female		
Grimm et al[23]		
Brushøj et al,[4] Ekstrand et al,[13] Emery and Meeuwisse,[14] Engebretsen et al,[15] Gilchrist et al,[19] Olsen et al,[49] Söderman et al,[60] Soligard et al,[61] Steffen et al,[63] Wedderkopp et al[78]	Knee and ACL injury incidence	Two of 10 studies showed a reduction in knee injuries[13,49] Four studies reported a nonsignificant increase in knee injuries in the intervention group[14,15,19,61] Two of 3 studies examining ACL injury incidence found decreases in number of injuries, but none found a significant reduction[19,49,60] One study showed a nonsignificant increase in ACL injuries in the intervention group[60] No evidence of publication bias
Myer et al[45]		
Gilchrist et al,[19] Heidt et al,[27] Hewett et al,[29] Kiani et al,[35] LaBella et al,[36] Mandelbaum et al,[42] Myklebust et al,[46] Olsen et al,[49] Pasanen et al,[51] Petersen et al,[52] Pfeiffer et al,[54] Söderman et al,[60] Steffen et al,[63] Waldén et al[77]	ACL injury incidence based on age	Overall, a significantly greater knee injury reduction in female athletes in intervention groups compared to controls (odds ratio = 0.54; 95% CI: 0.35, 0.83) Age dichotomized: under 18 y (odds ratio = 0.28; 95% CI: 0.18, 0.42; *P*<.01) and over 18 y (odds ratio = 0.84; 95% CI: 0.56, 1.26; *P* = .39) Age in tertiles: those aged 14-18 y had an odds ratio of 0.28 (95% CI: 0.18, 0.42; *P*<.01), those aged 18-20 y had an odds ratio of 0.48 (95% CI: 0.21, 1.07; *P* = .07), and those aged >20 y had an odds ratio of 1.01 (95% CI: 0.62, 1.64; *P* = .97) No evidence of publication bias
Stevenson et al[64]		
Gilchrist et al,[19] Heidt et al,[27] Hewett et al,[29] Kiani et al,[35] Mandelbaum et al,[42] Myklebust et al,[46] Petersen et al,[52] Pfeiffer et al,[54] Söderman et al,[60] Steffen et al[63]	ACL injury incidence	Two of 10 programs achieved a statistically significant decrease in ACL injuries[29,42] One study had a significant decrease in the incidence of ACL injuries during practices, late in the season, and in noncontact ACL injuries in those with a history of prior ACL injuries[19] Another study had a significant decrease in the ACL injury incidence in elite athletes[46] Two studies had significant decreases in the ACL injury rate among those who were deemed compliant with the program[46,63] One study had all noncontact ACL injuries in the control group, but no noncontact ACL injuries in the intervention group[52] One study had a significant increase in major knee injuries (80% of injuries in the intervention group)[60] One study had an increase in noncontact ACL injuries in the intervention group; however, it did not reach statistical significance.[54] When controlling for sport, this study had a 4-fold higher incidence of injuries in trained female basketball players than in control players Eight of the 10 studies included plyometric exercises[19,27,29,42,46,52,54,63] All 4 studies reporting some statistically significant decrease in ACL injuries included plyometrics, strength training, and flexibility[19,29,42,46] Only 1 of the studies that included plyometrics failed to show a decrease in ACL injuries[54] The 1 study that only included a balance component to the training had an increase in ACL injury incidence[60]

Table continues on page A38.

APPENDIX I

Sex/Review/Included Articles	Outcomes Examined	Findings
Sugimoto et al[67]		
Gilchrist et al,[19] Heidt et al,[27] Hewett et al,[29] Kiani et al,[35] LaBella et al,[36] Mandelbaum et al,[42] Myklebust et al,[46] Olsen et al,[49] Pasanen et al,[51] Petersen et al,[52] Pfeiffer et al,[54] Söderman et al,[60] Steffen et al,[63] Waldén et al[77]	ACL injury incidence	Eleven of 14 studies demonstrated fewer ACL injuries in intervention groups compared to controls[19,27,29,35,36,42,46,49,52,63,77] Exercise-based knee injury prevention programs that incorporated multiple exercise components had a greater ACL injury reduction (odds ratio = 0.32; 95% CI: 0.22, 0.46; $P<.01$) than those programs with only 1 exercise component (odds ratio = 1.15; 95% CI: 0.70, 1.89; $P = .59$) Balance exercises: there was no significant difference in the reduction in incidence of ACL injuries in neuromuscular training programs with balance exercises (odds ratio = 0.59; 95% CI: 0.42, 0.83; $P<.01$) compared to those with no balance exercises (odds ratio = 0.34; 95% CI: 0.20, 0.56; $P<.01$) Plyometric exercises: there was no significant difference in the reduction of ACL injury risk between neuromuscular training programs with plyometric exercises (odds ratio = 0.39; 95% CI: 0.26, 0.57; $P<.01$) compared to those with no plyometric exercises (odds ratio = 0.59; 95% CI: 0.39, 0.89; $P = .01$) Strength exercises: there was a significant reduction in the number of ACL injuries in neuromuscular training programs with strengthening exercises (odds ratio = 0.32; 95% CI: 0.23, 0.46; $P<.01$), but not in programs without strengthening (odds ratio = 1.02; 95% CI: 0.63, 1.64; $P = .95$) Proximal control exercises: neuromuscular programs that included proximal control exercises reduced ACL injuries (odds ratio = 0.33; 95% CI: 0.23, 0.47; $P<.01$). Programs that did not include proximal control exercises (odds ratio = 0.95; 95% CI: 0.60, 1.50; $P = .82$) did not reduce ACL injuries
Sugimoto et al[68]		
Gilchrist et al,[19] Heidt et al,[27] Hewett et al,[29] Kiani et al,[35] LaBella et al,[36] Mandelbaum et al,[42] Myklebust et al,[46] Olsen et al,[49] Pasanen et al,[51] Petersen et al,[52] Pfeiffer et al,[54] Söderman et al,[60] Steffen et al,[63] Waldén et al[77]	ACL injury incidence	Critical components of exercise-based ACL injury prevention programs: based on the odds ratios of previous studies, age (14-18 y), dosage (>20 min per training session), frequency (multiple times per week), and exercises (multiple exercise components) were deemed necessary attributes of prevention programs Using meta-regression, the authors found a 17% lower odds of an ACL injury if 1 of these 4 necessary components was included in a prevention program (odds ratio = 0.83; $\beta 1 = -0.29$; 95% CI: –0.33, –0.03; $P = .03$). This finding was similar when using a fixed-effects or random-effects model Age: there was a statistically greater ACL injury reduction in the mid teens (14-18 y) (odds ratio = 0.29; 95% CI: 0.19, 0.44; $P = .01$) compared to the early teens (<14 y) (odds ratio = 0.29; 95% CI: 0.01, 7.09; $P = .45$), late teens (18-20 y) (odds ratio = 0.48; 95% CI: 0.21, 1.07; $P = .07$), or in early adults (>20 y) (odds ratio = 1.01; 95% CI: 0.62, 1.64; $P = .97$)
Taylor et al[72]		
Gilchrist et al,[19] Heidt et al,[27] Hewett et al,[29] Kiani et al,[35] LaBella et al,[37] Mandelbaum et al,[42] Myklebust et al,[46] Olsen et al,[49] Petersen et al,[52] Pfeiffer et al,[54] Söderman et al[60]	Primary: ACL injury incidence (all and noncontact) Secondary: amount of time to complete program, season, age, presence of feedback, minutes per training session, total number of training sessions, AEs, player seasons, duration and variety of training exercises	Primary: statistically significant reduction in ACL injuries (odds ratio = 0.61; 95% CI: 0.44, 0.85) and noncontact ACL injuries (odds ratio = 0.35; 95% CI: 0.23, 0.54) when expressed as player seasons; statistically significant reduction in ACL injuries (odds ratio = 0.64; 95% CI: 0.42, 0.99) and noncontact ACL injuries (odds ratio = 0.38; 95% CI: 0.22, 0.64) when expressed in AEs Secondary: no effect of total training time or session duration on ACL injury rate; ACL injury risk increases as duration of balance exercises increases; injury risk decreases with greater emphasis on and longer duration of prescribed static stretching; no significant difference in injury incidence between programs where feedback was given compared to those where no feedback was given

Table continues on page A39.

APPENDIX I

Sex/Review/Included Articles	Outcomes Examined	Findings
Yoo et al[80]		
Heidt et al,[27] Hewett et al,[29] Mandelbaum et al,[42] Myklebust et al,[46] Petersen et al,[52] Pfeiffer et al,[54] Söderman et al[60]	ACL injury incidence	Pooling all studies, the authors found an odds ratio of 0.40 (95% CI: 0.27, 0.60), indicating that exercise-based knee injury prevention programs were effective at lowering odds of ACL injuries Subgroup analysis: prevention programs in athletes under 18 y (odds ratio = 0.27; 95% CI: 0.14, 0.49) were effective, but were not effective in athletes over 18 y (odds ratio = 0.78; 95% CI: 0.23, 2.64). Prevention programs in soccer players (odds ratio = 0.32; 95% CI: 0.19, 0.56) had a lower odds ratio than programs in team handball players (odds ratio = 0.54; 95% CI: 0.30, 0.97). Programs that began in the preseason and continued throughout the season were effective (odds ratio = 0.54; 95% CI: 0.30, 0.97) and had a higher odds ratio than programs that were in-season only (odds ratio = 0.32; 95% CI: 0.17, 0.59), but programs in the preseason only (odds ratio = 0.35; 95% CI: 0.10, 1.21) were not effective. Programs with plyometric (odds ratio = 0.37; 95% CI: 0.23, 0.55) and strengthening (odds ratio = 0.21; 95% CI: 0.11, 0.43) components were effective, and programs without these components (odds ratio = 0.69; 95% CI: 0.41, 1.15) were not. Programs without balance training (odds ratio = 0.27; 95% CI: 0.14, 0.49) were effective, and programs with balance components (odds ratio = 0.63; 95% CI: 0.37, 1.09) were not effective. No significant heterogeneity or publication bias was found

Abbreviations: ACL, anterior cruciate ligament; AE, athlete-exposure; CI, confidence interval.

APPENDIX J

EFFICACY OF EXERCISE-BASED KNEE INJURY PREVENTION PROGRAMS BY SPORT*

Sport/Study	Study Type	Subjects	Duration	Effect	Harms
Soccer					
Caraffa et al[5]	Cohort	n = 600 semi-professional and amateur soccer players in Umbri and Marche, Italy Age and sex not provided	30 d during preseason (20 min, every day)	Significant difference in injury incidence between intervention and control teams (*P*<.01) Intervention teams, 0.15 ACL injuries per season; control teams, 1.15 ACL injuries per season	None
Gilchrist et al[19]	Cluster RCT	Control, n = 852 Intervention, n = 583 NCAA Division I female soccer players; mean age, 19.9 y	12 wk through collegiate soccer season (15-20 min, 3 times per week)	Overall, no significant difference in injury rates for all knee injuries (*P* = .86) or ACL injuries (*P* = .20) The intervention group had a lower ACL injury rate in practices (*P* = .01), a lower late-season ACL injury rate (*P* = .03), and a lower rate of noncontact ACL injuries in those who reported a history of previous ACL injury (*P* = .05) No difference between groups in the injury rates during games (*P* = .62), early in the season (*P* = .93), or among those with no history of prior ACL injury (*P* = .43)	One player tripped during the lateral hops and had a tibial and fibular fracture, after which the cone height used was adjusted to be shorter
Grimm et al[22]	Meta-analysis†	Knee and ACL injury prevention programs tested in level I RCTs only in soccer players	Not available	Pooled relative risk for knee injuries = 0.74; 95% CI: 0.55, 0.98; *P* = .04; pooled relative risk for ACL injuries = 0.66; 95% CI: 0.33, 1.32; *P* = .24	None
Hewett et al[29]	Cohort	Female intervention, n = 97 Female control, n = 193 Male control, n = 209 High school–aged soccer players	6 wk during preseason (60-90 min, 3 times per week)	Serious knee injuries in soccer players only: trained females, 0; untrained females, 0.56/1000 AEs; untrained males, 0.12/1000 AEs	None
Kiani et al[35]	Cohort	Intervention, n = 777 Control, n = 729 Female soccer players aged 13-19 y	4 mo (approximately 20-25 min, twice per week, during preseason and once per week during the regular season)	Knee injuries: intervention incidence, 0.04/1000 h; control, 0.20/1000 h; unadjusted rate ratio = 0.23 (95% CI: 0.04, 0.83); rate ratio adjusted for compliance = 0.17 (95% CI: 0.04, 0.64) Noncontact knee injuries: intervention, 0.01/1000 h; control, 0.15/1000 h; unadjusted rate ratio = 0.10 (95% CI: 0.00, 0.70); rate ratio adjusted for compliance = 0.06 (95% CI: 0.01, 0.46) There were no ACL injuries in the intervention group	None

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Sport/Study	Study Type	Subjects	Duration	Effect	Harms
Mandelbaum et al[42]	Cohort	Year 1: intervention, n = 1041; control, n = 1905 Year 2: intervention, n = 844; control, n = 1931 Female soccer players aged 14-18 y	Throughout soccer season (20 min; the authors did not report recommended number of times per week)	Overall injury incidence of ACL injuries for the intervention group was 0.09/1000 AEs, and for the control group was 0.49/1000 AEs, over the 2-y study Relative risk = 0.18, *P*<.01 When broken down by year: year 1, 89% reduction in ACL injuries (relative risk = 0.11, *P*<.01); year 2, 74% reduction in risk (relative risk = 0.26, *P*<.01)	None
Pfeiffer et al[54]	Cohort	Intervention, n = 189 Control, n = 244 Female high school–aged soccer players	Throughout high school soccer season (20 min; the authors did not report the recommended number of times per week)	No noncontact ACL injuries in intervention group Control group incidence of noncontact ACL injuries, 0.107/1000 AEs	None
Waldén et al[77]	Stratified RCT	Intervention, n = 2479 Control, n = 2085 Female soccer players aged 13-17 y	Throughout soccer season (15 min, twice per week)	64% reduction in ACL injuries in intervention group (rate ratio = 0.36; 95% CI: 0.15, 0.85; *P* = .02) When adjusted for compliance, 83% reduction in ACL injuries (rate ratio = 0.17; 95% CI: 0.05, 0.57; *P*<.01), 82% reduction in severe knee injury (rate ratio = 0.18; 95% CI: 0.07, 0.45; *P*<.01), 47% reduction in all acute knee injuries (rate ratio = 0.53; 95% CI: 0.30, 0.94; *P* = .03)	None
Team handball					
Achenbach et al[1]	Block RCT	Intervention, n = 168 Control, n = 111 15- to 17-year-old team handball players; male and female	Throughout 1 handball season (15 min, 2-3 times per week, throughout the season)	Outcome of interest was severe knee injuries (intra-articular fracture, patellar subluxation, rupture of the collateral or cruciate ligament, meniscus tear, or cartilage injury that led to more than 28 d of absence from sport), 0.04/1000 h Control-group injury incidence, 0.33/1000 h; intervention group, 0.04/1000 h Intervention led to a significant decrease in severe knee injuries (odds ratio = 0.11; 95% CI: 0.01, 0.90; *P* = .02)	None
Myklebust et al[46]	Cohort	Control season, n = 942 First intervention season, n = 855 Second intervention season, n = 850 Female Norwegian team handball league players; mean age not provided	Throughout team handball season, including preseason (15 min, 3 times per week, during preseason and once per week during regular season)	Control-season ACL injury incidence, 0.14/1000 playing hours; first-intervention-season ACL injury incidence, 0.13/1000 playing hours; second-intervention-season ACL injury incidence, 0.06/1000 playing hours No significant difference in injury rate (odds ratio = 0.52; 95% CI: 0.15, 1.82; *P* = .31) When adjusted for compliance, there was a significant decrease in odds of injury in the elite division (odds ratio = 0.06; 95% CI: 0.01, 0.54; *P* = .01)	None

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Sport/Study	Study Type	Subjects	Duration	Effect	Harms
Olsen et al[49]	Cluster RCT	Intervention, n = 958 Control, n = 879 Female team handball players aged 16-17 y	Throughout one 8-mo team handball season (15-20 min, 15 consecutive training sessions at the start of the season, followed by once per week for the remainder of the season)	Significant reduction in all injuries (relative risk = 0.49; 95% CI: 0.39, 0.63; *P*<.01), lower extremity injuries (relative risk = 0.51; 95% CI: 0.36, 0.73; *P*<.01), and acute knee injuries (relative risk = 0.45; 95% CI: 0.35, 0.81; *P*<.01) Number of athletes needed to treat to prevent 1 injury was 11; number of athletes needed to treat to prevent 1 acute knee injury was 43 Significant reduction in knee ligament injuries (relative risk = 0.20; 95% CI: 0.06, 0.70; *P* = .01); nonsignificant reduction in meniscal injuries (relative risk = 0.27; 95% CI: 0.06, 1.28; *P* = .10)	None
Basketball					
Hewett et al[29]	Cohort	Female intervention, n = 84 Female control, n = 189 Male control, n = 225 High school–aged basketball players	6 wk during the preseason (60-90 min, 3 times per week)	Incidence of serious knee injuries in basketball players: trained females, 0.42/1000 AEs; untrained females, 0.48/1000 AEs; untrained males, 0.08/1000 AEs No significant difference in the number of serious knee injuries between trained and untrained females (*P* = .89) There was a trend toward fewer noncontact knee injuries in trained females (*P* = .05)	None
Pfeiffer et al[54]	Cohort	Intervention, n = 191 Control, n = 319 Female high school–aged basketball players	Throughout high school basketball season (20 min; the authors did not report the recommended number of times per week)	Basketball control group, 0.111/1000 AEs; basketball intervention group, 0.476/1000 AEs	None
Volleyball					
Hewett et al[29]	Cohort	Female intervention, n = 185 Female control, n = 81 High school–aged volleyball players	6 wk during the preseason (60-90 min, 3 times per week)	No serious knee injuries in any volleyball players in this study, thus unable to make any comparison	None
Pfeiffer et al[54]	Cohort	Intervention, n = 197 Control, n = 299 Female high school–aged volleyball players	Throughout high school volleyball season (20 min; the authors did not report the recommended number of times per week)	No noncontact ACL injuries in any volleyball players in this study, thus unable to make any comparison	None

Abbreviations: ACL, anterior cruciate ligament; AE, athlete-exposure; CI, confidence interval; NCAA, National Collegiate Athletic Association; RCT, randomized controlled trial.

Programs are organized by sport, and only the results related to the specific sport are presented in this table. Full results of each program are listed in* **TABLE 3.

†Included studies: Ekstrand et al,[13] Emery and Meeuwisse,[14] Engebretsen et al,[15] Gilchrist et al,[19] Söderman et al,[60] Soligard et al,[61] Steffen et al,[63] van Beijsterveldt et al,[74] Waldén et al.[77]