What Is the Most Effective Training Approach for Preventing Noncontact ACL Injuries in High School–Aged Female Athletes?

Erica M. Willadsen, Andrea B. Zahn, and Chris J. Durall

Clinical Scenario: A variety of training approaches have been adopted in anterior cruciate ligament (ACL) prevention programs, including neuromuscular control training, core stability training, balance training, and plyometric exercise. This review was conducted to determine if current evidence supports one of these training approaches over the others for reducing noncontact ACL injuries in adolescent female athletes. Focused Clinical Question: What is the most effective training approach for preventing noncontact ACL injuries in adolescent and/or high school–aged female athletes? Summary of Key Findings: A literature search generated 2 level 1b randomized control trials and 1 level 2b cohort study. Plyometric training resulted in decreased knee valgus during landing in 3 studies and increased knee flexion at landing in 2 studies. Balance training or neuromuscular training led to decreased knee valgus and increased knee-flexion angles with landing in 2 studies. Core stability training had conflicting effects on knee valgus and knee-flexion angles at landing, with 1 study reporting no effect and another reporting an undesirable decrease in knee joint flexion angle at landing. Clinical Bottom Line: Based on this review, plyometric training, balance training, and neuromuscular training approaches appear sensible to include in ACL prevention programs for female athletes to help decrease knee valgus and knee flexion during landing. Core stability training may be somewhat beneficial for decreasing knee valgus angles at landing, although may have nominal or even deleterious effects on knee-flexion angle at landing, and thus should be implemented with caution. Strength of Recommendation: Our recommendations were derived from the results of 2 level 1b randomized control trials and 1 level 2b cohort study.

Keywords: anterior cruciate ligament, kinematics, landing, physical therapy, prevention, young adult

Clinical Scenario
The high prevalence of noncontact anterior cruciate ligament (ACL) injuries in adolescent female athletes is thought to originate from hormonal, neuromuscular, and structural differences between sexes.1 Although hormonal and structural factors are nonmodifiable, neuromuscular control can be altered with training. A variety of training approaches have been adopted in ACL prevention programs, including neuromuscular control training, core stability training, balance training, and plyometric exercise. A common goal of these prevention programs is to reduce knee valgus and increase knee flexion during landing, cutting, or jumping activities to moderate ACL strain. This review was conducted to determine if current evidence supports one of these training approaches over the others for reducing noncontact ACL injuries in adolescent female athletes.

Focused Clinical Question
What is the most effective training approach for preventing noncontact ACL injuries in adolescent and/or high school–aged female athletes?

Summary of Search, “Best Evidence” Appraised, and Key Findings
• A literature search was performed for studies that compared disparate ACL prevention programs to determine the most effective training paradigm for reducing noncontact ACL injury risk.
• The search generated 2 level 1b randomized control trials (RCTs) and 1 level 2b cohort study. These studies examined the effects of plyometric exercise, balance training, core stabilization training, and neuromuscular control training on hip and knee mechanics previously shown to correlate with an elevated risk of ACL injury.
• Plyometric training resulted in decreased knee valgus during landing in all 3 of the reviewed studies2–4 and increased knee flexion at landing in 2 of these studies.2,3 In contrast, one of the studies found decreased landing knee-flexion angles in response to plyometric training.4 Balance training or neuromuscular training led to decreased knee valgus and increased knee-flexion angles with landing in 2 studies.2,3 Core stability training had conflicting effects on landing knee valgus, with 1 study reporting a training-related decrease in valgus angulation5 and another reporting no change in landing knee valgus angle.2 Results were also inconsistent regarding the effects of core stability training on knee-flexion angle at landing, with 1 study reporting no effect2 and another reporting an undesirable decrease in knee joint flexion angle at landing.4
Clinical Bottom Line

The risk of noncontact ACL injury is thought to be elevated during landing, cutting, or jumping with increased knee valgus and/or increased knee extension angulation.1,3 Based on this review, plyometric training appears sensible to include in ACL prevention programs for female athletes to help decrease knee valgus during landing.2–4 Plyometric training also appears beneficial for helping to increase knee flexion at landing.2,3 It is noteworthy that 1 study in this review showed a negative effect of plyometric training on landing knee-flexion angulation.4 Balance training or neuromuscular training can also be recommended for ACL injury prevention programs to help decrease knee valgus angles and increase knee-flexion angles at landing.3,4 Core stability training may be somewhat beneficial for decreasing knee valgus angles at landing,4 although it appears to have nominal or even deleterious effects on knee-flexion angle at landing,2,4 and thus should be implemented with caution. Based on the reviewed studies, plyometric, balance, neuromuscular, or core stability training should occur 2 to 3 times a week for at least 4 weeks to produce putatively desirable kinematic changes.2–4 Additional studies are needed to assess the impact of these training programs on ACL injury rates after the training period.

Strength of Recommendation

Our recommendations were derived from the results of 2 level 1b RCTs and 1 level 2b cohort study.

Search Strategy

Terms Used to Guide the Search Strategy

• Patient/Client group: adolescent and/or high school–aged female athletes (age 13–18 y)
• Intervention: anterior cruciate ligament; ACL; injury prevention; plyometric training
• Comparison: other ACL injury preventative approaches/paradigms
• Outcome(s): noncontact ACL tears or kinematic measures putatively associated with elevated noncontact ACL injury risk

Sources of Evidence Searched (Databases)

• PubMed
• MEDLINE
• EBSCOhost
• Google Scholar

Table 1 Summary of Study Designs of Articles Retrieved

<table>
<thead>
<tr>
<th>Level of evidence</th>
<th>Study design</th>
<th>Number located</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1b</td>
<td>Randomized control trial</td>
<td>2</td>
<td>Brown et al2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Myer et al3</td>
</tr>
<tr>
<td>2b</td>
<td>Cohort study</td>
<td>1</td>
<td>Pifle et al4</td>
</tr>
</tbody>
</table>

Inclusion and Exclusion Criteria

Inclusion Criteria

• Limited to adolescent and/or high school–aged females (13–18 y old)
• Noncontact ACL injuries
• Comparison of disparate ACL prevention programs
• Outcome measures that included sagittal or frontal plane knee kinematics or rates of noncontact ACL injury after intervention period
• Limited to last 11 years (2006–2017)

Exclusion Criteria

• Studies outside the English language
• Studies strictly comparing a control group rather than an intervention group
• Participants with previous ACL or other knee injury

Results of Search

A total of 3 studies, 2 RCTs and 1 cohort study, satisfied the inclusion criteria for this review (Table 1). All the 3 studies compared the effects of different ACL injury prevention training approaches/paradigms on kinematic variables previously found to be associated with an elevated risk of noncontact ACL injury.

Best Evidence

The articles in this review included 2 level 1b RCTs and 1 level 2b study. Evidence levels were based on Centre for Evidence-Based Medicine 2009 criteria.5 These 3 articles, summarized in Table 2, were identified as the best evidence for this review.

Summary of Best Evidence

Key: ACL (anterior cruciate ligament), IR (internal rotation), ER (external rotation), LE (lower-extremity).

Implications for Practice, Education, and Future Research

An estimated 100,000 to 250,000 ACL injuries occur each year in the United States.1 Most of these injuries are thought to be noncontact in origin. A concerted effort is ongoing to identify contributory factors and remediate them through preparticipation training programs. The objective of our review was to determine if the literature-based evidence supports a particular injury prevention paradigm. Unfortunately, none of the reviewed studies assessed the impact of training on future ACL injuries. Instead, the investigators analyzed how the training programs affected hip and knee mechanics during controlled landing activities. Therefore, there is no direct evidence that these training programs reduce ACL injuries.
Conclusion

Plyometric training may be beneficial for reducing ACL injury risk by helping to increase knee-flexion angles and decrease hip adduction/knee valgus angles at landing. Neuromuscular control training likewise should be considered for helping decrease hip adduction/knee valgus angles at landing. Core stability/balance training did not affect knee valgus angles or knee-flexion angles at landing.

Main findings

After 6 wk of training, plyometric training resulted in a statistically significant decrease in hip adduction from baseline \((P = .01, d = 0.83)\) during bilateral landings. Plyometric and neuromuscular training both resulted in an increase in knee flexion \((P = .01, d = 0.63\) and \(P = .03)\) and \(d = 0.56\), respectively) with the neuromuscular group impacting bilateral landings and the plyometric group impacting unilateral and bilateral landings. Overall, bilateral landings resulted in greater hip-flexion \((P < .001)\) and knee-flexion angles \((P < .001)\) than unilateral landings. No significant pre-postdifferences were found for the core stability/balance group or the control.

Outcome measure(s)

Peak knee-flexion and extension angles; peak hip flexion, extension, abduction, adduction angles; and peak joint moments during single- and double-leg landings. Landings were followed by an aggressive single-leg jump laterally or by a maximal vertical jump.

Study design

Randomized control trial

Level of evidence PEDro 7/10

Participants

43 females, age 13–18 y, randomly assigned to plyometric training \((n = 13)\), neuromuscular training \((n = 10)\), core stability and balance training \((n = 7)\), or control \((n = 13)\). No statistically significant difference was found between groups at baseline.

Intervention(s) investigated

Subjects participated in 1 of 4 groups: (1) 60 min of standard neuromuscular training (including 3 specific 20-min components of core strength and balance, plyometric, resistance, and speed training) (2) 20 min of isolated plyometric training (including double- and single-leg landing tasks to develop control of center of mass) (3) 20 min of core stability/balance protocol (including a focus on increased coordination, strength, and stability of lumbopelvic musculature) (4) The control group performed their normal daily activities.

Study design

Random assignment, controlled laboratory study

Level of evidence PEDro 7/10

Participants

18 high school female athletes, average age 14.8 years old randomly assigned to plyometric \((n = 8)\) or balance training \((n = 10)\). No statistically significant difference was found between groups at baseline.

Intervention(s) investigated

Plyometric group: maximum effort plyometric jumping and cutting maneuvers. Balance group: dynamic stabilization and balance exercises to strengthen lower extremities. Both interventions received task-specific oral feedback to improve postural control or the technique of their jumping and cutting movements.

Outcome measure(s)

Hip adduction, knee abduction, knee flexion, and ankle eversion. Measures were calculated at initial contact and maximum joint angle during a drop vertical jump and a medial drop landing.

Main findings

After 7 wk of training, both plyometric and balance protocols decreased lower-extremity valgus, specifically at the hip at initial contact \((P = .002, d = 0.6)\) and the hip at maximum joint angle \((P = .02, d = 1.1)\) during the double-leg drop vertical jump; knee valgus also decreased at initial contact and at the maximum joint angle \((P = .002, d = 1.5\) and \(P = .04, d = 1.6)\) during the single-leg medial drop landing. Similarly, both protocols resulted in increases in knee flexion at maximum joint angle, with plyometric training \((P = .05)\) impacting knee angles during the drop vertical jump and balance training \((P = .01)\) impacting knee angles during the medial drop landing.

Conclusion

Plyometric training and balance training may be beneficial at reducing ACL injury risk since both training modes were found to decrease lower-extremity valgus and increase knee-flexion angles during both unilateral and bilateral landing tasks.

Main findings

After 4 wk of training, the plyometric group demonstrated differences solely at the knee \((\text{hip flexion } d = −1.79, \text{knee internal rotation } d = −3.68, \text{knee- } \text{flexion moment } d = 2.04, \text{and knee abduction } d = 1.52)\). The core stability group demonstrated differences at the hip and knee \((\text{knee-flexion angle } d = −1.88, \text{knee internal rotation } d = 1.65, \text{hip- } \text{flexion moment } d = −1.51, \text{and hip internal rotation moment } d = −2.21). Both plyometric and core stability training induced a decrease in knee valgus angle and a decrease in knee joint flexion angle at landing.

Outcome measure(s)

Lateral trunk flexion angle, hip-flexion, adduction, and internal rotation angles, and knee flexion, abduction, and internal rotation angles during the landing phase of a drop vertical jump.

Study design

Cohort study

Level of evidence PEDro 7/10

Participants

23 high school female athletes, assigned to plyometric training \((n = 9)\), core stability training \((n = 8)\), or control \((n = 6)\). Groups were similar in age, height, and weight at baseline.

Intervention(s) investigated

Plyometric program: double-leg jumping, single-leg jumping, and skipping exercises focused on quality and form. Core stability program: improve neuromuscular control of abdominal, lumbar, and hip muscles to alter lower-extremity and trunk biomechanics. Control group: continued their normal team activities.

Abbreviation: ACL, anterior cruciate ligament.

**Table 2 Characteristics of Included Studies**

<table>
<thead>
<tr>
<th>Study design</th>
<th>Level of evidence</th>
<th>Participants</th>
<th>Intervention(s) investigated</th>
<th>Outcome measure(s)</th>
<th>Main findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown et al²</td>
<td>1b</td>
<td>43 females, age 13–18 y, randomly assigned to plyometric training ((n = 13)), neuromuscular training ((n = 10)), core stability and balance training ((n = 7)), or control ((n = 13)). No statistically significant difference was found between groups at baseline.</td>
<td>Subjects participated in 1 of 4 groups: (1) 60 min of standard neuromuscular training (including 3 specific 20-min components of core strength and balance, plyometric, resistance, and speed training) (2) 20 min of isolated plyometric training (including double- and single-leg landing tasks to develop control of center of mass) (3) 20 min of core stability/balance protocol (including a focus on increased coordination, strength, and stability of lumbopelvic musculature) (4) The control group performed their normal daily activities.</td>
<td>Peak knee-flexion and extension angles; peak hip flexion, extension, abduction, adduction angles; and peak joint moments during single- and double-leg landings. Landings were followed by an aggressive single-leg jump laterally or by a maximal vertical jump.</td>
<td>After 6 wk of training, plyometric training resulted in a statistically significant decrease in hip adduction from baseline ((P = .01, d = 0.83)) during bilateral landings. Plyometric and neuromuscular training both resulted in an increase in knee flexion ((P = .01, d = 0.63) and (P = .03)) and (d = 0.56), respectively) with the neuromuscular group impacting bilateral landings and the plyometric group impacting unilateral and bilateral landings. Overall, bilateral landings resulted in greater hip-flexion ((P &lt; .001)) and knee-flexion angles ((P &lt; .001)) than unilateral landings. No significant pre-postdifferences were found for the core stability/balance group or the control.</td>
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</tbody>
</table>

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injury risk. There is a need for additional investigations to pros-
pectively study the impact of these training paradigms, alone and
in combination, on the occurrence of noncontact ACL injuries.
Additionally, since the findings of this review can only be gener-
aлизed to adolescent or high school-aged female athletes, there is a
need to study the impact of training on future ACL injuries with
postadolescent females and various male populations as well.

Landing, cutting, or jumping with excessive hip adduction,
internal rotation, and/or knee hyperextension is thought to produce
most noncontact ACL injuries.1,3 Hewett et al1 found that elevated
hip adduction and knee valgus angulation upon landing predicted
ACL injury risk with a sensitivity of 78% and specificity of 73%.
The risk of noncontact ACL injury is also thought to be elevated
when the knee is extended during sudden deceleration and accel-
eration tasks.1,3 Accordingly, efforts to reduce noncontact ACL
injuries through training activities have focused on decreasing knee
valgus angulation and increasing hip and knee-flexion angulation
during transitional movements.5

The 3 studies reviewed to answer our clinical question all
found that plyometric training coupled with instruction on landing
technique and oral feedback significantly decreased knee valgus
angles after 4 to 7 weeks of training.2–4 Given this, plyometric
training appears promising for modulating noncontact ACL injury
risk. Balance training or neuromuscular training were also found to
help decrease knee valgus angles at landing in 2 of the reviewed
studies, and thus appear to be sensible for ACL injury prevention
programs.2,3 Core stability training had conflicting results on knee
valgus angles at landing. Pfiele et al4 reported a decrease in knee
valgus angles at landing, whereas Brown et al2 reported that knee
valgus angles were unchanged after core stability training.
Differences in the training protocols between these studies may
have contributed to the disparity in outcomes. It is also plausible
that the impact of core stability training on landing knee valgus
angulation is nominal.

Core stability training also produced conflicting results
between the reviewed studies for landing knee-flexion angulation.
Core stability combined with balance training had no effect on
knee-flexion angles during landing in the Brown et al study.2
Conversely, Pfiele et al4 reported that core stability training resulted
in decreased knee flexion at landing—a presumably undesirable
effect. Additional research is needed to ascertain if the benefits of
core stability training on knee valgus angulation at landing out-
weigh the potentially deleterious effects of this training mode on
knee-flexion angulation.3 Until further data are available, core
stability training should be implemented with caution in ACL
injury prevention programs.

Balance training or neuromuscular training should be consid-
ered for ACL injury prevention programs to help increase knee-
flexion angles at landing.2,3 Plyometric training was found to be
beneficial for helping to increase knee flexion at landing in 2 of
the reviewed studies,2,3 although the third study showed a negative
effect on landing knee-flexion angulation.4 Additional research is
needed to resolve this disparity.

Although it is plausible that combining multiple training
programs in an ACL injury prevention program would be more efficacious than using a single paradigm alone, supportive
data are sparse. Mandelbaum et al6 prospectively studied the
impact of the Prevent Injury and Enhance Performance (PEP)
program on ACL tears in a group of young female soccer players.
The PEP program utilizes aspects of several prevention programs
(stretching, strengthening, plyometric exercise, and sports-specific
agility drills) to address proprioceptive and biomechanical deficits
that are often seen in young female athletes. Mandelbaum et al6
found that the PEP group sustained 4 ACL tears (0.13 incidence
rate) at the 2-year follow-up, whereas the control group had 35
ACL tears (0.51 incidence rate), corresponding to an overall
reduction in tears of 74% in the PEP group.

In all 3 studies, participants in the plyometric and balance
groups received verbal feedback during their training programs,
which presumably contributed to the overall training effects. In the
study by Myer et al,3 for instance, the plyometric group received
ongoing verbal cueing to prevent knee valgus with maximal effort
jumping and to decrease knee valgus during cutting maneuvers.
The balance group in that study received instruction on how to
improve postural and lower-extremity alignment and how to soften
landings.3 Similarly, the other 2 reviewed studies utilized oral
feedback to encourage subjects to minimize knee valgus and knee
extension when landing.2,4 Specifically, participants were cued to
discourage knee valgus and encourage controlled knee flexion with
cutting, jumping, or landing maneuvers.2,4 Future researchers could
study the impact of utilizing various types of feedback (eg, verbal,
visual, and auditory), in conjunction with the training programs, on
landing knee mechanics.

The inconsistent terminology and differing protocols in the
reviewed studies makes it difficult to compare the training pro-
grams. Brown et al2 employed “neuromuscular control training” to
increase the power and strength of larger upper- and lower-body
muscle groups with the use of resistance bands and medicine balls.
The balance training techniques utilized in 2 of the studies suggest
that their intent was to enhance lower-extremity control of the
center of mass over the base of support (eg, BOSU® ball single-leg
squat, BOSU® ball deep knee-flexion hold).2,3 Core stabilization
exercises were intended to strengthen abdominal and lumbo-pelvic
musculature (eg, side-lying hip external rotation, crunches) in the
studies by Brown et al2 and Myer et al.3 Conversely, it appears
that plyometric training was more or less consistently utilized in the
studies to decrease knee valgus and lower-extremity contact forces
during landing (eg, box jumps, jump squats).3 Identifying the
unique qualities of each ACL injury prevention program is helpful
in determining the most effective exercises.

All 3 of our sources reported using a force plate to obtain
kinetic data, although it is unclear if or how any of these training
programs impacted vertical ground reaction force (vGRF).2–4 An
inverse relationship between vGRF and knee-flexion angle during
landing tasks has previously been identified.2 Future research
should include vGRF as an outcome measure, because high
vGRF during landings may increase the risk of ACL injury.7

References

1. Hewett TE, Myer GD, Ford KR, Paterno MV, Quatman CE. Mech-
anisms, prediction, and prevention of ACL injuries: cut risk with
1843–1855. doi:10.1002/jor.23414
2. Brown TN, Palmieri-Smith RM, McLean SG. Comparative adapta-
tions of lower limb biomechanics during unilateral and bilateral
landings after different neuromuscular-based ACL injury prevention
10.1519/JSC.0000000000000472
3. Myer GD, Ford KR, McLean SG, Hewett TE. The effects of
plyometric versus dynamic stabilization and balance training on

