

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

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**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.<sup>1</sup> 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?

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## 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 studies<sup>2–4</sup> and increased knee flexion at landing in 2 of these studies.<sup>2,3</sup> In contrast, one of the studies found decreased landing knee-flexion angles in response to plyometric training.<sup>4</sup> Balance training or neuromuscular training led to decreased knee valgus and increased knee-flexion angles with landing in 2 studies.<sup>2,3</sup> Core stability training had conflicting effects on landing knee valgus, with 1 study reporting a training-related decrease in valgus angulation<sup>4</sup> and another reporting no change in landing knee valgus angle.<sup>2</sup> Results were also inconsistent regarding the effects of core stability training on knee-flexion angle at landing, with 1 study reporting no effect<sup>2</sup> and another reporting an undesirable decrease in knee joint flexion angle at landing.<sup>4</sup>

## 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.<sup>1,3</sup> Based on this review, plyometric training appears sensible to include in ACL prevention programs for female athletes to help decrease knee valgus during landing.<sup>2-4</sup> Plyometric training also appears beneficial for helping to increase knee flexion at landing.<sup>2,3</sup> It is noteworthy that 1 study in this review showed a negative effect of plyometric training on landing knee-flexion angulation.<sup>4</sup> 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.<sup>2,3</sup> Core stability training may be somewhat beneficial for decreasing knee valgus angles at landing,<sup>4</sup> although it appears to have nominal or even deleterious effects on knee-flexion angle at landing,<sup>2,4</sup> 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.<sup>2-4</sup> 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**

Level of evidence	Study design	Number located	Reference
1b	Randomized control trial	2	Brown et al <sup>2</sup> Myer et al <sup>3</sup>
2b	Cohort study	1	Pfile et al <sup>4</sup>

- SPORTDiscus
- Additional resources found using a manual search from several reference lists

## 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.<sup>5</sup> 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.<sup>1</sup> 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 training 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

**Table 2 Characteristics of Included Studies**

	<b>Brown et al<sup>2</sup></b>	<b>Myer et al<sup>3</sup></b>	<b>Pfifer et al<sup>4</sup></b>
Study design	Randomized control trial	Random assignment, controlled laboratory study	Cohort study
Level of evidence	1b	1b	2b
PEDro	7/10	7/10	NA
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.	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.	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	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.	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.	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.
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 bilateral maximal vertical jump.	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.	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.
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–post differences were found for the core stability/balance group or the control.	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.	After 4 wk of training, the plyometric group demonstrated differences solely at the knee (knee flexion $d = -1.79$ , knee internal rotation $d = -3.68$ , knee-flexion moment $d = 2.04$ , and knee abduction $d = 1.52$ ). The core stability group demonstrated differences at the hip and knee (knee-flexion angle $d = -1.88$ , knee internal rotation $d = 1.65$ , hip-flexion moment $d = -1.51$ , 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.
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.	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.	Plyometric training and core stability training both resulted in a decrease in knee valgus angle at landing and thus should be considered for ACL injury prevention programs. However, both training programs led to a decrease in knee joint flexion angle at landing, which is likely to increase ACL strain.

Abbreviation: ACL, anterior cruciate ligament.

injury risk. There is a need for additional investigations to prospectively 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 generalized 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.<sup>1,3</sup> Hewett et al<sup>1</sup> 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 acceleration tasks.<sup>1,3</sup> 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.<sup>1</sup>

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.<sup>2-4</sup> 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.<sup>2,3</sup> Core stability training had conflicting results on knee valgus angles at landing. Pfile et al<sup>4</sup> reported a decrease in knee valgus angles at landing, whereas Brown et al<sup>2</sup> 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.<sup>2</sup> Conversely, Pfile et al<sup>4</sup> 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 outweigh the potentially deleterious effects of this training mode on knee-flexion angulation. 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 considered for ACL injury prevention programs to help increase knee-flexion angles at landing.<sup>2,3</sup> Plyometric training was found to be beneficial for helping to increase knee flexion at landing in 2 of the reviewed studies,<sup>2,3</sup> although the third study showed a negative effect on landing knee-flexion angulation.<sup>4</sup> Additional research is needed to resolve this disparity.

Although it is plausible that combining multiple training programs in an ACL injury prevention training program would be more efficacious than using a single paradigm alone, supportive data are sparse. Mandelbaum et al<sup>6</sup> 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 al<sup>6</sup> 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,<sup>3</sup> 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.<sup>3</sup> Similarly, the other 2 reviewed studies utilized oral feedback to encourage subjects to minimize knee valgus and knee extension when landing.<sup>2,4</sup> Specifically, participants were cued to discourage knee valgus and encourage controlled knee flexion with cutting, jumping, or landing maneuvers.<sup>2,4</sup> 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 programs. Brown et al<sup>2</sup> 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<sup>®</sup> ball single-leg squat, BOSU<sup>®</sup> ball deep knee-flexion hold).<sup>2,3</sup> Core stabilization exercises were intended to strengthen abdominal and lumbopelvic musculature (eg, side-lying hip external rotation, crunches) in the studies by Brown et al<sup>2</sup> and Myer et al.<sup>3</sup> 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).<sup>3</sup> 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).<sup>2-4</sup> An inverse relationship between vGRF and knee-flexion angle during landing tasks has previously been identified.<sup>7</sup> Future research should include vGRF as an outcome measure, because high vGRF during landings may increase the risk of ACL injury.<sup>7</sup>

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