Anterior cruciate ligament (ACL) injuries are common in athletes, costly, and potentially debilitating. It is estimated that 1 in every 3,000 persons injure his or her ACL and approximately 95,000 new ACL injuries occur each year, although the statistical validity of these estimates has been questioned, and sources in the medical-supply industry suggest much higher numbers. Individuals who suffer ACL injury and undergo surgical intervention face a lengthy rehabilitation process ranging from 6 to 36 months. Unfortunately, surgical intervention does not ensure a return to previous activity levels. Only 75% of these individuals return to their previous activity levels. Moderate to severe disability is reported in individuals suffering from ACL injury during walking activities (31%), routine activities of daily living (44%), and sport activities (77%). The outlook might be worse for individuals who do not undergo surgical intervention after ACL injury. Untreated ACL injuries (nonsurgical, ACL-deficient) often lead to devastating impairment, with two-thirds of these injuries resulting in chronic knee instability, secondary meniscal- and chondral-surface damage, and early onset of osteoarthritis. It has been reported that individuals suffering acute knee injury, such as ACL injury, are 7.4 times more likely to develop knee osteoarthritis than those with no history of knee injury. Ultimately, the disability associated with ACL injury can lead to reduced physical activity levels and loss of independence. In addition to disability, ACL injury places a large financial burden on the health-care system, with health-care costs reported to be as high as $2.5 billion annually. The frequency, disability, and excessive cost associated with ACL injury make it a significant health concern. Thus, there is a great need to prevent ACL injuries from occurring.

The rate of ACL injury is greater in females than males, especially in younger individuals. Research indicates that females who are involved in recreational, as well as organized physical, activities injure their ACLs at a rate of 2 to 5 times greater than that in males. Some studies have reported a rate in females over 10 times greater than the male rate, but they are based on small numbers of ACL injuries and should be regarded as tentative. The risk of ACL injury is greater in younger individuals (e.g., high school and college age). Data on ACL-reconstruction procedures by candidates for the certification of the American Board of Orthopaedic Surgeons suggest that more ACL-reconstruction procedures are performed for high-school- and college-age individuals than any other age group.
times more than that for older women, and the number of such procedures for high-school- and college-age males is 1.5 times that of older men. These data indicate that high-school- and college-age females appear to be at greatest risk for ACL injury. As the number of females participating in competitive and recreational physical activity continues to increase, the number of female ACL injuries can be expected to increase. Given the frequency, disability, cost, and higher rate of injury, it is necessary to develop interventions to reduce ACL injury rates, especially in younger females.

Over the past several years there has been an increasing amount of research investigating the influence of various exercise programs on ACL-injury rates or risks. There does not, however, appear to be a consensus on the effectiveness of these exercise programs for reducing the incidence of ACL injury. To provide clinicians with evidence for incorporating ACL-injury-prevention exercises we systematically reviewed the literature for studies investigating the influence of exercise programs (e.g., strength, flexibility, plyometrics, agility, balance, proprioception) on ACL-injury prevention. We assessed data from randomized controlled trials, cohort studies, and cross-sectional studies that evaluated exercise programs.

**Literature-Review Methods**

We searched the literature to locate all articles meeting set eligibility criteria (see the sidebar). The methods used to locate the articles included an electronic literature search of the PubMed database and a manual search of the reference lists of known published review articles. All articles that met the eligibility criteria were reviewed, and the data on ACL injury were abstracted from each article.

**Electronic Literature Search**

For the electronic literature search, we used the PubMed database maintained by the National Library of Medicine. The search terms used are listed in the sidebar. These search criteria yielded an initial total of 821 articles. The titles and abstracts (where electronically available) for these articles were individually reviewed to determine their eligibility.

**Manual Literature Search**

In addition to the systematic search, an effort was made to manually locate articles meeting the eligibility criteria. We were aware, through our familiarity with the ACL literature, of a number of articles that met these criteria. We accessed these and reviewed their reference lists. In addition, we reviewed the reference lists of several recent review articles to identify additional articles that met the eligibility criteria.

**Search Results and Data Abstraction**

We located nine articles that met the eligibility criteria. We reviewed each study and abstracted the relevant data. The type of information abstracted for each study is shown in the sidebar.

**Evaluating Individual Articles and Body of Evidence**

Each study was evaluated according to the guidelines of strength-of-recommendation taxonomy, which were developed by editors from several family-practice-related journals and represent a patient-centered approach to grading evidence in the medical literature. An individual study was assigned a grade of 1–3.
to rate the level of evidence it provided (Tables 1[a] and 1[b]).35 Once we had reviewed each individual study and assigned a grade to it we provided a rating for the entire body of evidence. Based on the body of evidence reviewed we assigned a rating of A, B, or C35 to the following recommendation: “ACL injury-prevention-training programs involving exercise can be used to reduce the risk of ACL injury.”

### Exercise Programs to Prevent ACL Injuries

In addition to the studies located through the literature and manual searches, we also included a cross-sectional case series by Charles Henning as part of the systematic review.36 The case series presented by Henning was believed to represent the initial work investigating the training effects on ACL-injury incidence and provided key insight into the ability to prevent ACL injury through training. Thus, we included this case-series study for historical context on ACL-injury-prevention training. A review of each study is presented in the following section, followed by the overall rating of the body of evidence to support the use of ACL-injury-prevention exercise programs.

Two main types of preventive training programs have been published for ACL injury: proprioception-balance training31-34,37 and plyometric-agility training.27-30 Proprioception-balance training is designed to improve one’s coordination and balance by performing exercises that include, but are not limited to, balancing on one leg, balancing on an unstable platform, and single-leg balancing while perform various tasks involving the upper extremity (Figure 1). Plyometric-agility

<table>
<thead>
<tr>
<th>Table 1(a). Rating Criteria Used to Evaluate Level of Evidence for Individual Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Individual-Study Evidence Rating</strong></td>
</tr>
</tbody>
</table>
| Level 1 | Good-quality patient-oriented evidence  
Meta-analyses of randomized controlled trials with consistent findings 
High-quality randomized controlled trials |
| Level 2 | Limited-quality patient-oriented evidence  
Meta-analyses of lower quality clinical trials, inconsistent findings 
Lower quality clinical trials 
Cohort study 
Case-control study |
| Level 3 | Other evidence  
Consensus guidelines 
Extrapolations from bench research 
Usual practice 
Opinion 
Disease-oriented evidence 
Case studies |

<table>
<thead>
<tr>
<th>Table 1(b). Rating Criteria Used to Evaluate the Body of Evidence as a Whole (SORT Guidelines)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Body-of-Evidence Rating</strong></td>
</tr>
<tr>
<td>Level A, strong evidence</td>
</tr>
<tr>
<td>Level B, moderate evidence</td>
</tr>
</tbody>
</table>
| Level C, weak evidence | Consensus 
Usual practice 
Disease-oriented evidence 
Case studies |

**Figure 1**  Proprioception-balance-training exercises commonly involve single-leg balancing tasks. These exercises can be modified by having individuals perform multiplanar reaching with the non-weight-bearing leg (as pictured). Other common modifications involve using foam pads, wobble boards, and incorporating upper extremity movements (e.g., ball toss, reaching).
training is designed to improve an individual’s agility, dynamic stability, and technique during dynamic tasks. Typically, plyometric-agility exercises involve performing various jumping, landing, and cutting maneuvers in different planes of motion and at varying intensity levels. Other common training techniques incorporated in ACL-injury-prevention exercise programs are technique-movement awareness training,27,28,31,32 strength training,27,28,30 and flexibility training.28,30

Proprioception-Balance Training

Caraffa et al.26 performed a cohort study investigating the influence of balance training on ACL-injury incidence (Level 2 evidence). The participants in this study were male amateur and semiprofessional soccer players in Italy. The balance-training program consisted of a series of balance exercises on wobble boards, step-ups in the anteroposterior direction, and a neuromuscular-facilitation technique that was not described by the authors. Each balance-training session lasted approximately 20 min and was performed on a daily basis during the preseason. Once the soccer season started, the balance exercises were performed just three times per week. After the soccer season there were 70 arthroscopically verified ACL injuries in the control group that did not undergo balance training, whereas there were only 10 arthroscopically verified ACL injuries in the balance-training group (p < .001). This study is limited in that there was no randomization to group assignment and only male soccer athletes were included in the sample. In addition, it is not clear if compliance was monitored in the balance-training group. The benefit of this study is that the balance-training program used could readily be implemented in the clinical setting.

In a separate study investigating balance training in soccer athletes, Soderman et al.33 implemented a randomized controlled trial (Level 2 evidence) in female soccer players. This study did not specifically investigate ACL injury but, rather, investigated overall injury patterns. The female soccer players were given their own balance boards and were provided with a printed handout of the training program. The balance-training program was carried out as a home exercise program that took approximately 10–15 min to complete. The balance-training program consisted of five separate single-leg balance exercises of increasing difficulty. Individuals were instructed to perform three trials of single-leg balance for 15 s on each leg. The exercises were to be performed on a daily basis before the beginning of the soccer season. Exercise frequency was decreased to three times per week once the soccer season began. Contrary to the findings of Caraffa et al.26 (with male soccer players), there was no difference between the control and intervention groups in the incidence of traumatic injuries, number of injuries, type of injuries, or time to first injury. Soderman et al. indicated that a possible reason for the differences in their findings compared with those of Caraffa et al. were the differences in gender, playing division, or total amount of balance training between the two studies. There was insufficient statistical power to specifically investigate ACL injuries; however, there were a greater number of “major” injuries (unable to participate in games or practices for more than 30 days) in the balance-training group than in the control group (p = .02). Of particular interest was the finding that four of the five ACL injuries experienced were in participants in the balance-training group. This appears to be the only study that has demonstrated a greater number of injuries in individuals who have participated in an injury-prevention exercise program.

The strengths of Soderman et al.’s33 study were that the female soccer teams were randomly assigned to groups and the balance-training program used could be readily implemented in any clinical setting; however, there are still several limitations to the study. The balance-training program was a home exercise program, and there was no way of monitoring compliance, so it was unclear whether the participants actually performed the exercises on a regular basis. In addition, the authors did not indicate exposure data for the reported injuries or whether the injuries were contact or non-contact in nature. This information might have important implications on the finding of greater numbers of “major” injuries in the balance-training group.

Multiple studies emphasizing balance training have been conducted on handball athletes. A cohort study incorporating a phased intervention was performed by Myklebust et al.31 over the course of 3 years (1998–2001; Level 2 evidence). The 1998–1999 handball season served as the control season, and no prevention training was instituted during this time period. During the control season, injury data were collected on 60 teams from different handball divisions (12 teams from the elite and second divisions and 36 teams from the third division) using an injury-surveillance system. Coaches and team physical therapists reported all ACL injuries. Patients’ medical records were obtained to confirm the diagnosis of ACL
injury. After the control season were two intervention seasons (1999–2000 and 2000–2001) during which individuals in the training groups performed a five-phase balance-training program of increasing difficulty. Each of the intervention-group teams was supplied with an instructional video, posters, six balance mats, and six wobble boards. During a 5- to 7-week period before the start of the handball season the teams were instructed to perform the balance program three times per week. Once the handball season began, the teams were instructed to perform the program once a week. The coaches carried out the training programs, and physical therapists were recruited to supervise each of the teams and monitor compliance. Each balance-training session took approximately 15 min to complete. Players were instructed to focus on proper technique, movement awareness, and body positioning during the intervention. Similar to the control season, an injury-surveillance system was used to record ACL injuries, and teams from the three different handball divisions were represented during the intervention seasons.

In the study by Myklebust et al.,31 29 ACL injuries were recorded during the control season, compared with 23 and 17 ACL injuries during the first and second intervention seasons, respectively. There was no difference in the incidence of ACL injuries between the control and balance-training groups (p > .05). To further investigate the influence of balance training on ACL-injury incidence, the authors separated the groups by skill level (elite, second, and third division) and completion of the balance-training program (completion = 15 training sessions completed and 75% player participation). In the elite division, the risk of ACL injury decreased in the handball athletes who completed the balance-training program (p = .01). Thus, this study demonstrates that ACL injuries can be prevented in elite handball athletes who complete the balance-training program, but the effectiveness of the program was concentrated in the elite athletes—the risk of ACL injury was relatively unaffected in less skilled handball athletes (second and third division). The major limitation of this study was that individuals were not randomly assigned to either a control or an intervention group. In addition, the authors did not provide demographic information (gender, age, height, weight) for their participants. In particular, the participants’ gender and age are important information when considering the generalizability of these findings. In light of these limitations there are several strengths to this study, including closely monitored compliance, systematic injury-surveillance system, collection of exposure data, and a balance-training program that can be implemented in the clinical setting.

Balance-training-related research in handball athletes using randomized controlled trials has also been conducted. These studies investigated overall injuries, however, and did not specifically investigate ACL injuries.32,34 Wedderkopp et al.34 (Level 2 evidence) recruited 16 teams and 163 handball athletes between the ages of 14 and 16 years. Teams were randomly assigned to one of two groups that were matched according to skill level (elite, intermediate, and recreational level): functional strength training (8 teams, n = 86) and functional strength and balance training (8 teams, n = 77). The authors did not describe the functional-strength program other than to state that the program focused on all major muscle groups. The balance training was performed using a personal ankle disk for 15 min, followed by two or more functional-strength activities. Injury data were collected by conducting a weekly review with the coaches from each team in the study. If a player was identified as being injured, the player was contacted by a physician and interviewed to determine the type, location, and severity of the injury. If some doubt remained about the injury after the interview, a physician then examined the injured player. Over the course of the handball season the group that underwent balance training and functional strengthening had significantly fewer traumatic injuries (e.g., sprains; p = .04), as well as fewer moderate (absent from practice and games from 1 week to 1 month) and major (absent from practice and games for more than 1 month) injuries (p = .03). There was no difference in numbers of overuse injuries (e.g., ten-dinitis) between the two groups. Limitations of this study include a lack of detail provided in describing the exercise programs, no description of the participants’ gender, no focus on ACL injury, and a lack of detail in describing specific injury types.

The strongest study investigating the effects of balance training was recently published by Olsen et al.32 (Level 1 evidence). The study’s primary limitation is that, because of a lack of statistical power, the authors were not able to specifically focus on ACL injuries. Nonetheless, this study has many positive qualities (e.g., randomization, exposure data, detailed description of intervention, compliance monitoring, detailed description of injury characteristics, and a detailed description of injury-data-collection procedures) and could be used as a model for future research investigat-
ing ACL-injury prevention through exercise. A cluster randomized controlled trial was used in a group of adolescent male and female handball athletes (age range 15–17 years). A total of 123 handball clubs participated in this study and were randomly assigned to the intervention or control group. The groups were matched according to region, playing level, gender, and number of athletes. The intervention program consisted of a dynamic warm-up, technique training, balance training, and strength/power training. The entire intervention took 15–20 min and was performed on a daily basis for 15 consecutive sessions during the preseason and then once a week during the remainder of the season. During the dynamic warm-up participants performed a single 30-s trial of jogging, backward running, forward running, sideways running with leg cross-over (“carioca”), sideways running with arms lifted (“parade”), forward running with trunk rotations, forward running with intermittent stops, and a speed run. After the dynamic warm-up, participants performed 4 min of technique training including cutting, planting, and jump-landing tasks. During technique training the participants were instructed to be focused and aware of the quality of their movements, maintain the “knee over toe” position, and perform two-foot landings. Next, balance training using foam mats or wobble boards was performed for 4 min. Participants performed ball passes (two-legged and single-legged), squats (two-legged and single-legged), ball dribbling with eyes closed, and perturbation training by pushing each other during the balance exercises. Finally, plyometric/strength training was performed by incorporating squats, bounding strides, forward jumps, jump shot (two-legged landing), and “Nordic hamstring lowers” (reverse hamstring curls). This training program was very similar to the program used by Myklebust et al.,\(^1\) but Olsen et al. emphasized dynamic warm-up and strengthening more.

Over the course of the handball season, Olsen et al.’s\(^2\) intervention group experienced significantly fewer injuries overall, acute injuries overall, acute knee or ankle injuries, knee-ligament injuries (not ACL-injury specific), and noncontact acute injuries (\(p < .05\)). In addition, the intervention group experienced less severe injuries than the control group. This study is unique from the previous balance-training programs in that it used a multifaceted exercise program including a dynamic warm-up (agility training), technique training, and plyometric/strength training in addition to balance training. The time required (15–20 min) and necessary equipment (foam mats, wobble boards) for this program make it particularly appealing to implement in the clinical setting as part of a prepractice warm-up routine. Details of the Olsen training program are available on the Web at http://www.ostrc.no/ostrc.asp?aidresource_p.

**Plyometric-Agility Training**

Hewett et al.\(^{27}\) first investigated the influence of plyometric-agility training using a cohort study design (Level 2 evidence). For a single playing season, 1,263 high school soccer, basketball, and volleyball athletes participated in this study. The athletes were assigned to one of three groups: female intervention group (volleyball = 185, soccer = 97, basketball = 84), female control group (volleyball = 81, soccer = 193), or male control group (soccer = 209, basketball = 225). The intervention consisted of a jump-training program lasting 60–90 min per session that was performed 3 days per week over a 6-week period. The jump-training program was implemented in phases: (1) technique training (Weeks 1–2); (2) strength, power, and agility training (Weeks 3–4); and (3) performance training focused on maximizing vertical-jump height (Weeks 5–6). During each training phase various jumping exercises were performed to achieve the desired goals in addition to stretching and strengthening exercises. Injury-exposure data were collected for all participants. The authors collected injury data on serious knee injuries (at least 5 consecutive days lost from sport participation) and noncontact knee injuries. Over the course of the playing season, 14 serious knee injuries were recorded for all sports. Chi-square analyses demonstrated a significantly higher incidence of serious knee injury in the control groups than in the female intervention group (\(p = .05\)). Of the 14 serious knee injuries, 9 were reported as noncontact in nature. Chi-square analyses demonstrated a significantly higher incidence of serious noncontact knee injury in the untrained control groups than in the female intervention group (\(p = .01\)). Six noncontact ACL injuries occurred over the course of the study (5 female control participants and 1 male control participant). Based on the chi-square analyses, the number of noncontact ACL injuries occurring in the female intervention group was significant (\(p = .05\)).

There are several limitations to Hewett et al.’s\(^{27}\) study. First, groups were not randomly assigned. Second, the groups were not matched according to sport participation. Most participants in the female intervention group were volleyball players. In contrast,
the control groups consisted primarily of soccer and basketball players. This might be a confounding factor to these findings because female volleyball players are at a lower risk of ACL injury than soccer and basketball players are. A third major limitation is the low number of noncontact ACL injuries sustained (six total). It might be inappropriate to draw conclusions based on only six noncontact ACL injuries. Finally, Hewett et al. were also criticized in the literature for performing inappropriate statistical analyses given the number of participants sustaining ACL injury in the training group (letters to the editor, *Am J Sports Med*. 2000;28[4]:615-617 and 28[6]: 918-920). Although their findings are very promising, the results of this study must be considered in light of these limitations.

More recent research has continued to explore the effects of plyometric-agility training in adolescent soccer players. These studies have not focused specifically on ACL injuries, but this research demonstrates a reduction in the number of injuries experienced in the intervention groups in comparison with the control groups. Using a randomized-controlled-trial design, Heidt et al. recruited 300 female high school soccer players (age range 14–18 years) and randomly assigned 42 of them to an intervention group. The intervention group’s training program consisted of cardiovascular conditioning, plyometric training, sport-cord drills, strength training, flexibility exercises to improve speed and agility, and acceleration training focused on learning proper techniques and skills. The program was carried out over a 7-week period, but information was not provided regarding specific exercises performed, the time duration of a single training session, or exposure data. Fourteen percent of the intervention-group participants experienced an injury, compared with 33% in the control group. The authors used a Student’s *t* test to compare the occurrence of injury between groups and indicated a significantly greater occurrence of injury in the control group (*p* = .008). The lack of exposure data combined with the unequal number of participants per group (control = 258, intervention = 42) might be significant limitations to these findings. Specifically, it might be inappropriate to compare the raw number of injuries (not adjusted for exposure) between groups when there are 6 times as many participants in the control group as in the intervention group.

Junge et al. (Level 2 evidence) used a nonrandomized cohort study design in adolescent male soccer players (age range 14–19 years). The intervention group (*n* = 101) performed the F-MARC Bricks program. This program consists of 10 sets of exercises that aim to improve stability of the ankle and knee joints; flexibility of the trunk, hip, and leg muscles; reaction time; and endurance. Initially, the program emphasized raising motivation and awareness for injury-prevention strategies. This study is unique in that the intervention group underwent baseline screening for flexibility, speed, strength, and endurance. The screening measures were used to instruct individuals on how to improve on any individual weaknesses. To our knowledge, this is the only study that has attempted to address individual deficiencies as part of the training program. The control group participants (*n* = 93) were similar to the intervention group in terms of skill levels, number of previous injuries, and almost all baseline measures. The intervention group experienced significantly fewer injuries (20% lower) and had a lower rate of injury per player (36% lower) than the control group did. Nearly all injury types (mild, overuse, and noncontact injuries) were less frequent in the intervention group than in the control group. The authors also analyzed the effects of the intervention by skill level and demonstrated that the incidence of injury in low-skilled intervention-group participants was lower than that in the highly skilled intervention-group participants, which suggests that the low-skilled players might have benefited more from the intervention than the highly skilled players did. This finding seems to contradict Myklebust et al., who revealed that the incidence of ACL injury was reduced in highly skilled handball players who underwent the intervention but not in the low-skilled handball players. It should be emphasized that Junge et al. did not specifically investigate ACL injuries and included male soccer athletes, whereas Myklebust et al. studied female handball players, and such differences might account for the inconsistencies between the findings in these two studies.

The most recently published study investigating plyometric-agility training is a nonrandomized cohort study by Mandelbaum et al. (Level 2 evidence). This was a 2-year study (2000–2001) that involved 5,703 female soccer players (age range 14–18 years) who were placed in either the intervention (*n* = 1,885, teams = 97) or control (*n* = 3,818, teams = 207) group. The groups were matched according to age and skill level. This study is unique in that it is the first to focus specifically on noncontact ACL injuries. All participants in the intervention group received an educational videotape that demonstrated the 20-min warm-up pro-
program that was to be performed before soccer practice and games. In addition, all coaches attended a training session in which the “Prevent Injury and Enhance Performance (PEP)” training program was described. The training program consisted of three warm-up activities (jog, shuttle run, and backward running), five stretching exercises (calf, quadriceps, hamstrings, hip adductors, and hip flexors), three strengthening exercises (walking lunges, Russian hamstring lowers, and single-toe raises), five plyometric exercises (lateral cone hops, forward cone hops, single-leg cone hops, vertical jumps, and scissor jumps), and three agility exercises (shuttle run, diagonal run, and bounding run). A heavy emphasis was placed on proper technique by stressing “soft landings,” large amounts of hip and knee flexion, and avoidance of “flat foot” landings. Expert modeling of the exercises was demonstrated in the instructional videos, as well as poor technique. The team coach designed the warm-up routine for the control-group participants. Exposure data were collected for all participants, and specified criteria for confirming a noncontact ACL were included, which involved injury history, physical examination by a physician, and positive MRI or arthroscopic-examination findings. There was a significant decrease in noncontact ACL injuries in the intervention compared with the control group. During the first and second years of the study there were dramatic decreases, 88% and 74%, respectively, in noncontact ACL injuries for the intervention group. The major limitation of this study is the lack of random assignment of participants to either the control or the intervention group. In spite of this limitation this study presents strong data to suggest that noncontact ACL were included, which involved injury history, physical examination by a physician, and positive MRI or arthroscopic-examination findings. There was a significant decrease in noncontact ACL injuries in the intervention compared with the control group. During the first and second years of the study there were dramatic decreases, 88% and 74%, respectively, in noncontact ACL injuries for the intervention group. The major limitation of this study is the lack of random assignment of participants to either the control or the intervention group. In spite of this limitation this study presents strong data to suggest that noncontact ACL injuries might be prevented in adolescent female soccer players undergoing a plyometric-agility training program. To further validate these findings a randomized controlled trial is needed that incorporates the same training procedures.

Discussion

Our systematic review of published evidence of exercise programs to prevent ACL injuries demonstrates that there is Level B evidence to support the use of specialized exercise programs incorporating proprioception-balance and/or plyometric-agility exercises to decrease the rate of ACL injuries. Level B evidence represents moderate evidence based on inconsistent or limited-quality studies focused on patient-oriented evidence (e.g., ACL injury rates). All of the published evidence included in this systematic review were Level 2 (limited quality patient-oriented evidence) except the recent study by Olsen et al. (Level 1 evidence), but Olsen et al. did not investigate ACL injuries.

Of the studies reviewed, only three appeared to have adequate statistical power to examine the effects of an ACL injury-prevention-training program on ACL injuries. Although each of these studies demonstrated the ability to reduce ACL-injury risk by implementing a training program, none were randomized controlled trials. Thus, although each of these three studies provides great insight into potential methods of preventing ACL injury, the strongest evidence to support the use of these training programs should be based on randomized controlled trials. The randomized-controlled-trial studies reviewed provide moderate evidence to support the use of exercise programs emphasizing proprioception-balance and plyometric-agility training for overall injury prevention, but not specifically ACL injury. Only one study did not demonstrate a reduction in injury risk after implementation of a training program. Despite improved balance after completing the proprioception-balance-training program ($p = .04$) the findings of Soderman et al. revealed no difference in the incidence of traumatic lower extremity injuries between female soccer players in the intervention and control groups. In addition, the study provides the only evidence to suggest that an injury-prevention exercise program might increase the risk of injury. Specifically, participants in the intervention group were at greater risk for sustaining “major” traumatic lower extremity injuries in comparison with the control group. It is unclear why the findings of Soderman et al. are in such contrast to the other studies. The proprioception-balance training program they used was similar to programs employed in other studies. Thus, the exercise program itself would not seem to be a factor. The population studied (female soccer players) was also similar to previous studies. The only notable difference was that the female soccer players in Soderman et al.’s study appeared to be significantly older (intervention = 20.4 ± 4.6 years, control = 20.5 ± 5.4) than in other studies (average age range 14–18 years). We do not believe, however, that this would be a contributing factor to explain these differences. Thus, based on our review there appears to be strong evidence to indicate that injury-prevention training programs incorporat-
ing proprioception-balance and/or plyometric-agility exercises do not increase the risk of injury. Based on the authors’ descriptions and the aspects emphasized during training for each of the exercise programs, we labeled the different injury-prevention programs as being primarily proprioception-balance or plyometric-agility based. Most of the training programs were not purely proprioception-balance or plyometric-agility based; rather, combinations of different exercises were used in most programs. An important aspect common to nearly all programs was their emphasis on proper technique while performing the exercises and raising the individuals’ awareness about potentially injurious movement patterns. Individuals are educated on what represents good and poor technique (Figure 2). Common elements emphasized during technique and movement-awareness training included avoiding knee valgus (“knees over toes”), maintaining neutral tibial rotation (“toes pointed straight ahead”), maximizing knee and hip flexion (“bend your knees and hips), and landing softly (“land light as a feather”). The concept of teaching proper technique and promoting injury-risk awareness was first introduced in a cross-sectional case series by Charles Henning (Table 2; Level 3 evidence). Through the use of simple instruction regarding technique and injury awareness, Henning demonstrated an 89% decrease in ACL injuries sustained in a group of college basketball players. Specifically, the athletes were instructed to make rounded turns when cutting, maintain a flexed knee when landing, and use three steps to come to a complete stop. Based on the reviewed research studies and case series, it seems as if the most successful ACL-injury-prevention exercise programs incorporate a multifaceted exercise approach (proprioception-balance, plyometric-agility, strength, flexibility) and promote proper technique and injury-risk awareness above performance. It is not clear from the literature, however, whether a training program that uses a multifaceted exercise approach is any more beneficial than programs focused on a single type of exercise.

Although a multifaceted exercise program seems most beneficial, there is no research to indicate what are most important and essential components of an

![Figure 2](https://via.placeholder.com/150)

**Figure 2** Common elements of poor technique include landing with feet flat and little knee or hip flexion, landing with knee valgus, and performing single-leg balance exercises with poor body control (e.g., lateral trunk flexion, hip adduction, knee valgus).
<table>
<thead>
<tr>
<th>Study, Level</th>
<th>Design</th>
<th>Exercise</th>
<th>Intervention n</th>
<th>Sex</th>
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<th>Control n</th>
<th>Sex</th>
<th>Outcome</th>
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<tbody>
<tr>
<td>Caraffa, 26 Level 2</td>
<td>Cohort</td>
<td>Balance training using wobble boards</td>
<td>~300 (20 teams)</td>
<td>M</td>
<td>Soccer</td>
<td>~300 (20 teams)</td>
<td>M</td>
<td>10 ACL injuries in intervention group (0.15 injuries per team/ season) 70 ACL injuries in control group (1.15 injuries per team/ season)</td>
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<td>Soderman, 33 Level 2</td>
<td>RCT</td>
<td>Balance training using wobble boards</td>
<td>121</td>
<td>F</td>
<td>Soccer</td>
<td>100</td>
<td>F</td>
<td>No difference in the number, incidence, or type of traumatic injuries experienced between groups Incidence rate of “major” injuries greater in the intervention group (4 of 5 ACL injuries occurred in intervention group)</td>
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<td></td>
<td>RCT</td>
<td>Balance training using wobble boards and strength training</td>
<td>86</td>
<td>?</td>
<td>Handball</td>
<td>—</td>
<td>—</td>
<td>Fewer traumatic injuries (not specific to ACL injury) in the balance-/strength-training group than in the strength-training group</td>
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<tr>
<td></td>
<td>Strength training</td>
<td></td>
<td>77</td>
<td>?</td>
<td>Handball</td>
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<tr>
<td>Myklebust, 31 Level 2</td>
<td>Cross-sectional series</td>
<td>Balance training using foam mats and wobble boards, awareness training focused on proper landing technique</td>
<td>855 (1st season 1999–2000)</td>
<td>F</td>
<td>Handball</td>
<td>942 (control season 1998–1999)</td>
<td>F</td>
<td>For the entire cohort, no difference in ACL injury rates between control and intervention seasons In elite division, risk of ACL injury reduced in those who completed the training program</td>
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<td>850 (2nd season 2000–2001)</td>
<td>F</td>
<td>Handball</td>
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<tr>
<td>Author (Year)</td>
<td>Level</td>
<td>Study Type</td>
<td>Intervention</td>
<td>Participants</td>
<td>Injuries</td>
<td>Results</td>
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<td>Olsen, 32</td>
<td>Level 1</td>
<td>RCT</td>
<td>Balance training using foam mats and wobble boards, awareness training focused on proper landing technique, as well as strength training</td>
<td>808 F 150 M</td>
<td>Handball 778 F 101 M</td>
<td>The intervention group experienced less overall, lower limb, acute knee, acute ankle, and acute upper limb injuries (not specific to ACL injury)</td>
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<td>Hewett, 27</td>
<td>Level 2</td>
<td>Cohort</td>
<td>Plyometric jump training emphasizing technique, strength, power, agility, and maximum vertical-jump height</td>
<td>185 F 97 M 84 F</td>
<td>Volleyball 81 F 193 F, Soccer 189 F 209 M</td>
<td>Incidence of noncontact injuries (not specifically ACL injury) greater in female control group than in female intervention group</td>
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<td>Heidt, 28</td>
<td>Level 2</td>
<td>RCT</td>
<td>Soccer-specific cardiovascular, plyometric, strength and flexibility training to improve speed and agility; emphasize proper technique and avoidance of risky movements</td>
<td>42 F 258 F 153 M</td>
<td>Soccer 93 M</td>
<td>Occurrence of injury (not ACL injury specific) less in the intervention group than in the control group</td>
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<td>Junge, 29</td>
<td>Level 2</td>
<td>Cohort</td>
<td>Designed to improve ankle and knee stability, increase flexibility and strength of trunk, hip, and leg muscles, as well as improve coordination, reaction time, and endurance (F-MARC Bricks)</td>
<td>101 M</td>
<td>Soccer 93 M</td>
<td>20% fewer injured players (not ACL injury specific) in intervention group</td>
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<td>Mandelbaum, 30</td>
<td>Level 2</td>
<td>Cohort</td>
<td>Pre-practice warm-up routine focused on stretching, strengthening, plyometrics, and agility drills</td>
<td>1,885 F 3,818 F</td>
<td>Soccer</td>
<td>88% and 74% decrease in ACL injuries in the intervention group compared with the control group during 1st and 2nd years of study, respectively</td>
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<tr>
<td>Henning (unpublished), Level 3</td>
<td>Cross-sectional case series</td>
<td>Technique recommendations focused on making accelerated rounded turns, bent-knee landing, and 3-step stop with knees bent</td>
<td>? ?</td>
<td>Basketball</td>
<td>After instituting the technique training program, 89% decrease in occurrence of ACL injuries per year (# ACL injuries pretraining over 3 years for Teams 1 and 2 = 14; # ACL injuries postraining over an 8-year period for Team 1 = 2 ; # ACL injuries postraining over 3 years for Team 2 = 1)</td>
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effective ACL-injury-prevention exercise program the. In addition, there is a need to improve our understanding of the underlying mechanisms by which an ACL-injury-prevention exercise program might reduce injury risk. Recent research has started to address this issue. Other questions that should be addressed in future studies include (a) Can the effects of training programs be maximized by individualizing the exercise program to an individual’s needs (e.g., deficits in strength, flexibility, neuromuscular control) based on an initial assessment? (b) How long does a training program need to be performed to achieve the desired results? (c) How frequently (e.g., three times per week) does the training program need to be performed to achieve the desired results? (d) Should training programs be specific to an individual’s gender, age, sport, or injury history to achieve the desired results? (e) When is the appropriate time (e.g., preseason, in-season, out of season) to perform the training program? (f) What are the most important factors to successfully implementing a prevention exercise program in the clinical setting (e.g., length of program, type of program, coach’s approval)? (g) Does the risk of injury increase when an athlete stops performing an injury-prevention exercise program?

To strengthen the evidence supporting ACL-injury-prevention exercise programs and improve the effectiveness of these programs there is a need to perform high-quality randomized control trials in which ACL injury is the primary outcome. Authors should provide a detailed description of the participants and injury-prevention exercise program. It is possible that gender, age, sport, previous injury history, and other factors might influence the effects of injury-prevention programs. Thus, a detailed description of the participants recruited for a study is required to appropriately generalize the study’s findings. Also, the exercise program should be described in great detail and include the following information: description of each specific exercise, duration of each exercise, total duration of exercise program, number of sets and repetitions for each exercise, how participants were progressed over the course of the program, when exercises were implemented (e.g., preseason), and a description of equipment used during training. Compliance monitoring is also needed to ensure that individuals perform the exercise program at the specified time periods and with proper technique.

Finally, to allow for comparisons between studies, it is critical to standardize the way in which ACL-injury incidence is reported and how ACL injuries are identified. Researchers should give serious consideration to how the denominator (“exposure”) data are defined and collected and provide a detailed description of their denominator data (e.g., “exposure” to participation in sports). This will allow for future literature reviews to more readily compare and contrast the findings across studies. A full description of the ACL injuries is also necessary. Specifically, researchers should classify ACL injuries as being caused by direct contact (contact to knee causing injury), indirect contact (contact to upper extremity that caused loss of body control and resulted in injury), or noncontact (no contact to individual at time of injury). A description of how ACL injuries were verified for the study (e.g., arthroscopic examination, manual examination, patient history, MRI) is also required. By addressing each of these areas in future randomized controlled trials, we can develop a much stronger evidence base for ACL-injury-prevention exercise programs.

Conclusions

Although there are still many questions to be answered regarding the effectiveness of ACL-injury-prevention exercise programs, there is currently moderate evidence (Level B) to suggest that proprioception-balance and plyometric-agility training reduce ACL-injury risk. Clinicians, coaches, parents, and athletes should be encouraged to participate in these types of exercise programs because there is no consistent evidence to indicate that they do any harm. Exercise programs that achieve the greatest success in preventing injury seem to incorporate a multifaceted training approach by employing proprioception-balance and plyometric-agility exercises while simultaneously emphasizing proper technique and injury-risk awareness.

References


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