Journal of Athletic Training 2006;41(4):450–456

www.journalofathletictraining.org

Neuromuscular Control Training Programs and Noncontact Anterior Cruciate Ligament Injury Rates in Female Athletes: A Numbers-Needed-to-Treat Analysis

Terry L. Grindstaff; Robert R. Hammill; Ann E. Tuzson; Jay Hertel

University of Virginia, Charlottesville, VA

Terry L. Grindstaff, PT, DPT, ATC, CSCS; Robert R. Hammill, MS, ATC, CSCS; and Ann E. Tuzson, PT, MS, contributed to conception and design; acquisition and analysis and interpretation of the data; and drafting, critical revision, and final approval of the article. Jay Hertel, PhD, ATC, FACSM, contributed to conception and design, analysis and interpretation of the data, and critical revision and final approval of the article.

Address correspondence to Terry L. Grindstaff, PT, DPT, ATC, CSCS, University of Virginia, PO Box 400407, 210 Emmet St South, Charlottesville, VA 22904-4407. Address e-mail to tlg6q@virginia.edu.

Objective: To determine the numbers needed to treat (NNT) and relative risk reduction (RRR) associated with neuromuscular training programs aimed at preventing noncontact anterior cruciate ligament (ACL) injuries in female athletes.

Data Sources: We searched PubMed, MEDLINE, SPORT Discus, CINAHL, and Web of Science from 1966 through 2005 using the terms *knee, injury, anterior cruciate ligament, ACL, prevention, plyometric,* and *neuromuscular training.*

Study Selection: Selected articles were from peer-reviewed journals written in English that described original research studies comparing neuromuscular training programs with control programs to determine the number of noncontact ACL injuries per event exposure or hours of playing time. Five studies met the inclusion criteria and were independently rated by 3 reviewers using the Physiotherapy Evidence Database (PEDro) scale. Consensus PEDro scores ranged from 4 to 7 out of 10.

Data Extraction: We used numbers of subjects, ACL injuries, and injury exposure rates to calculate NNT and RRR for each study. The NNT calculations from all studies were based on the number of players across 1 competitive season and were described as NNT benefit or NNT harm.

Data Synthesis: All 5 studies demonstrated a prophylactic effect due to the neuromuscular training programs. The pooled NNT estimates showed that 89 individuals (95% confidence interval: 66 to 136) would need to participate in the prophylactic training program to prevent 1 ACL injury over the course of 1 competitive season. Pooled RRR was 70% (95% confidence interval: 54% to 80%) among individuals who participated in the intervention program. One high-quality randomized control trial and 4 medium-quality prospective cohort studies showed mostly consistent findings. Thus, a Strength of Recommendation Taxonomy level of evidence of 1 with a grade B recommendation supports the use of neuromuscular training programs in the prevention of noncontact ACL injuries in female athletes.

Key Words: knee injury, balance, plyometrics, injury prevention

Approximately 100 000 anterior cruciate ligaments (ACLs) are injured every year in the United States.[1] The cost of surgical repair and rehabilitation has been estimated at approximately $17 000 per case,[2] which does not include the medical costs associated with future complications, such as osteoarthritis or total knee arthroplasty, thought to occur more often in ACL-deficient or ACL-reconstructed knees.[3–5]

The rate at which ACL injury occurs among female athletes is very high compared with their male counterparts.[6] Estimates indicate that female athletes incur ACL ruptures at a rate of 0.06 to 0.24 per 1000 hours of athlete-exposures,[2,6–13] with the rate for ACL injuries in game situations being as high as 0.90 per 1000 hours of play.[8] When injury rates for females are compared with those of males, noncontact ACL injuries are 3 times greater in soccer players and 4 times greater in basketball players.[6] These injury rate differences between the sexes have been proposed to be associated with factors such as structural variations,[14] hormonal changes attributed to the menstrual cycle,[15,16] and differences in general laxity,[17,18] muscle activation ratios,[18] styles of play,[19] and kinetics and kinematics.[19] We must understand the potential influence of the sex discrepancy in order to employ prevention strategies aimed at decreasing the incidence of noncontact ACL injuries in female athletes.

Recently various intervention programs have been used to attempt to reduce the risk of ACL injuries.[2,7,9–11,13,20–22] Most of these intervention programs attempt to influence the neuromuscular system via plyometrics, strength training, or stretching exercises, as well as training balance and proper technique to subsequently prevent injuries. Neuromuscular training programs have demonstrated the ability to decrease associated risk factors for injury[23–28] and injury rates.[2,7,9–11,13,20–22]

When we examine interventions that decrease injury incidence, the numbers-needed-to-treat (NNT) statistic may be used to determine intervention effectiveness. The NNT is the

Table 1. Description of Intervention Programs

Reference	Design	Average PEDro Score*	Population	Intervention	Frequency	Duration, min	Instructional Training
Hewett et al[2]	Prospective, nonrandomized, cohort study	4	High school female soccer and basketball players	Three-phase program included flexibility, plyometrics, and weight training, with emphasis on technique, strength, power, agility, and performance	Three alternating d/wk, 6 wk before start of season	60 to 90	Certified athletic trainer and physical therapist demonstration of stretching and plyometric techniques with emphasis on proper form and coach and certified athletic trainer feedback regarding technique
Myklebust et al[9]	Prospective, nonrandomized, crossover study	4	Elite Norwegian female handball players	Five-phase program with 3 exercises (floor, balance mat, and wobble board)	Before practice, 3 d/wk for the first 5 to 7 wk, then 1×/wk for the remainder of the season	15	Instructional video and posters with physical therapist feedback regarding technique
Mandelbaum et al[13]	Prospective, nonrandomized, cohort study	5	Female soccer players, aged 14 to 18 y	Warm-up, stretching, strengthening, plyometrics, sport-specific agility drills	Before practice, 3×/wk	20	Instructional video and supplemental literature with emphasis on proper technique
Petersen et al[10]	Prospective, matched cohort study	4	Elite German female handball players	Six-phase balance board and jump training program	Before practice, 3×/wk in preseason, then 1×/wk for the season	10	Video and educational session regarding mechanism of anterior cruciate ligament injuries
Olsen et al[7]	Prospective, cluster randomized control trial	7	Female handball players, aged 15 to 17 y	Exercises with a ball, wobble board, and balance mat were used for warm-up, technique, balance, and strength/power	Before practice at every training session for first 15 sessions, then 1×/wk for the remainder of the season	15 to 20	Exercise books and single visit from an instructor from Handball Federation to improve awareness and control of knees and ankles

*PEDro indicates Physiotherapy Evidence Database.

estimate of how many individuals need to participate in an intervention program to prevent 1 adverse outcome.[29,30] Another statistic that can be used to express decreased injury rates, one that is easily interpreted by clinicians, is relative risk reduction (RRR). The RRR estimates the percentage of risk that is reduced for individuals who participate in an intervention program versus individuals in the control group.[29]

The number of individuals needed to participate in order to benefit from neuromuscular training programs and the programs' degrees of effectiveness are unknown at this time. The purpose of our systematic review was to determine the NNT and RRR associated with neuromuscular training programs aimed at preventing noncontact ACL injuries.

METHODS

Methods Literature Search

We searched PubMed (1966–2005), MEDLINE (1966–2005), SPORT Discus (1975–2005), CINAHL (1982–2005), and Web of Science (1981–2005) in October 2005 using combinations of the terms *knee, injury, anterior cruciate ligament, ACL, prevention, plyometric,* and *neuromuscular training*. Citations were also cross-referenced for identification of studies not found using the original search terms. A total of 972 articles were identified. We further limited the search by applying additional selection criteria: (1) publication in a peer-reviewed journal, (2) written in English, (3) inclusion of a control group, (4) use of neuromuscular training with an intended goal of preventing ACL injuries, and (5) an outcome measure of knee injuries per event exposure or hours of playing time.

After applying selection criteria, we identified 5 studies[2,7,9,10,13] for analysis. Selected studies were further independently evaluated by 3 coauthors using the Physiotherapy Evidence Database (PEDro) scale.[31] The PEDro scale is an objective method of evaluating the quality of research articles and has moderate reliability (intraclass correlation coefficient = 0.54, 95% confidence interval [CI] = 0.39 ± 0.71).[31,32] Articles were independently rated, and a consensus score was determined for each after-group discussion. Scores ranged between 4 and 7, with an average of 4.8 out of 10 (Table 1).

Calculations

Data related to the number of noncontact ACL injuries, number of athletes, and exposures were extracted from individual articles to calculate NNT and RRR and associated 95%

Table 2. Injury Rates, Numbers-Needed-to-Treat Analysis, and Relative Risk Reduction

Study	Noncontact Anterior Cruciate Ligament Injuries in Groups, No.	Female Athletes per Group, No.	Noncontact Anterior Cruciate Ligament Injury Incidence Rates in Groups*	Numbers Needed to Treat (Benefit)†	Numbers Needed to Treat (Benefit [NNTB] or Harm [NNTH]), 95% Confidence Interval	Relative Risk Reduction, %‡	Relative Risk Reduction, 95% Confidence Interval
Hewett et al[2] (soccer)							
Control	2	193	0.11	97	NNTB 33 to ∞ to NNTH 102	100	NA§
Intervention	0	97	0.00				
Hewett et al[2] (basketball)							
Control	3	189	0.14	63	NNTB 23 to ∞ to NNTH 92	100	NA
Intervention	0	84	0.00				
Myklebust et al[9]							
Control	18	942	0.09	109	NNTB 55 to 18569	48	−7 to 75
Intervention	17	1705	0.05				
Mandlebaum et al[13]							
Control	67	3818	0.24	70	NNTB 49 to 122	82	65 to 91
Intervention	6	1885	0.04				
Petersen et al[10]							
Control	5	142	0.21	28	NNTB 15 to 250	100	NA
Intervention	0	134	0.00				
Olsen et al[7]							
Control	5	778	0.06	193	NNTB 89 to ∞ to NNTH 1177	81	−69 to 98
Intervention	1	808	0.01				
Total							
Control	100	6163	0.16	89	NNTB 66 to 136	70	54 to 80
Intervention	24	4863	0.04				

*Per 1000 hours of athlete-exposures; when necessary, 1 event exposure was assumed to equal 2 hours.
†Numbers-needed-to-treat indicates 1/(injury incidence for control group − injury incidence for intervention group).
‡Relative risk reduction indicates 1 − (injury incidence for intervention group/injury incidence for control group).
§NA indicates not available.

CIs. The number of athletes per season and the number of injuries per group from each of the 5 studies were added to obtain a pooled estimate of effectiveness. Because most authors only examined female athletes,[9,10,13] and because only 1 male noncontact ACL injury occurred in a mixed-sex study,[2] we conducted further analysis using only the data regarding female noncontact ACL injuries.

To determine NNT, we first calculated the absolute risk reduction (ARR) using the control event rate (CER) minus the intervention event rate (IER). The inverse of the absolute risk reduction was used to calculate NNT values and was based on the number of players across 1 competitive season:

$$\text{ARR} = \text{CER} - \text{IER} \qquad \text{NNT} = \frac{1}{\text{ARR}}$$

A positive NNT value indicated a beneficial preventive effect due to the intervention, whereas a negative value indicated a harmful effect. Positive NNT values were described as NNT benefit (NNTB), and negative values were described as NNT harm (NNTH).[30] If the ARR was zero, then the NNT had values that approached infinity (∞), indicating that no preventive effect occurred and that an infinite number of individuals would have to be treated to benefit from the intervention.[30]

To calculate RRR, we first calculated the relative risk (RR) by using the ratio of the IER and CER. The RRR indicates the percentage by which the treatment reduces risk compared with the control.[29] Positive RRR values indicate reduced risk and negative values indicate increased risk compared with controls.

$$\text{RR} = \frac{\text{IER}}{\text{CER}} \qquad \text{RRR} = (1 - \text{RR}) \times 100$$

We determined the 95% CIs for the respective NNT and RRR values using an online statistical calculator (Clinical Significance Calculator; University of British Columbia, Vancouver, BC, Canada).[33]

RESULTS

Authors of articles selected for analysis examined a variety of athletes, at different skill levels, participating in basketball,[2] soccer,[2,13] and handball.[7,9,10] Injury prevention exercise regimens varied among programs and are detailed in Table 1. All researchers utilized some form of a control group, and the time frame of intervention program administration included preseason only,[2] in season only,[7,9,13] or the combination of preseason and in season.[10] Pertinent study data and calculations are presented in Table 2, and results for specific articles are listed in chronologic order.

Hewett et al

The authors of this prospective, nonrandomized, cohort study examined female and male high school basketball and soccer players over the course of 1 season. Teams elected to participate in either the intervention or control program. The intervention program was performed 3 times per week on alternating days for 6 weeks of the preseason. Each session was

60 to 90 minutes in duration and focused on flexibility, plyometrics, and weight training. A certified athletic trainer or physical therapist demonstrated proper exercise techniques and stressed proper form. Exposures were defined as exposure to risk of injury during 1 practice or game. Injuries were evaluated by a certified athletic trainer and a sports medicine physician and were confirmed with arthroscopic examination if necessary.

Over the course of the high school season, there were zero noncontact ACL injuries in the soccer and basketball intervention groups. Three noncontact ACL injuries occurred in the control soccer group and 3 noncontact ACL injuries in the control basketball group. An NNT analysis demonstrated that to prevent 1 noncontact ACL injury over the course of a season, 97 soccer players (95% CI = NNTB 33 to ∞ to NNTH 102) and 63 basketball players (95% CI = NNTB 23 to ∞ to NNTH 92) would have to participate in the intervention program. The RRR was 100% for both intervention groups. Calculations of CIs for RRR were not possible because zero injuries occurred in the intervention groups.

Myklebust et al

The investigators in this prospective, nonrandomized, crossover-design study evaluated elite Norwegian female handball players. The first year of the study (1998–1999) served as a control year to determine injury rates. The following 2 seasons (1999–2000 and 2000–2001) served as intervention years, in which athletes participated in a program consisting of 3 balance exercises at 5 levels of difficulty. The intervention program was performed for 15 minutes, 3 times per week, for the first 5 to 7 weeks and then 1 time per week after preseason intervention. Intervention consisted of a combination of running, jumping, agility, and balance exercises that emphasized proper technique. Before intervention seasons, teams were supplied with an instructional video, 6 balance mats, and 6 wobble boards. Athletes and coaches viewed the instructional video demonstrating and describing correct exercise techniques. This instructional session enabled peers and coaches to provide feedback regarding technique in conjunction with physical therapist supervision and feedback. Players were encouraged to perform tasks with correct technique, focusing on core, hip, and knee positions relative to the foot. Exposures were determined based on information collected from coaches. Competition exposure was determined by taking the product of the number of games multiplied by duration multiplied by 7 players per team. Practice exposures were based on average weekly training hours multiplied by average practice attendance. Injuries were confirmed by physical therapist and orthopaedic surgeon examination, with magnetic resonance imaging and arthroscopic examination if necessary.

During the control season, 18 noncontact injuries occurred, compared with 10 and 7 noncontact injuries for the next 2 intervention seasons, respectively. An NNT analysis showed that 109 athletes (95% CI = 55 to 18 569) would have to participate in an intervention program to prevent 1 noncontact ACL injury over the course of a season. The RRR was 48% (95% CI = −7% to 75%), which means the risk of a noncontact ACL tear was reduced by 48% among individuals who participated in the injury prevention program.

Mandelbaum et al

The authors of this prospective, nonrandomized, cohort study examined female soccer players, aged 14 to 18 years, over 2 competitive soccer seasons. Teams volunteered to participate in either the injury prevention program or control groups. The injury prevention program consisted of a 20-minute warm-up performed 3 times per week before practice sessions. The program included stretching, strengthening, plyometrics, and sport-specific agility drills. Before program initiation, players watched a videotape demonstrating and emphasizing proper technique and examples of improper technique. Coaches attended an introductory educational meeting outlining details of the injury prevention program and were given materials to conduct the program. Exposures were recorded by coaches on a weekly basis and were defined as practices or games during which the athlete was exposed to the risk of athletic injury. Potential injuries were reported by coaches and evaluated by a physician and confirmed with magnetic resonance imaging and/or arthroscopic examination.

Over 2 seasons, 6 noncontact ACL injuries occurred in the intervention group and 67 in the control group. To prevent 1 noncontact ACL injury over the course of a season, 70 athletes (95% CI = 49 to 122) would have to participate in an intervention program. The RRR for noncontact ACL injury was 82% (95% CI = 65% to 91%) among individuals who participated in the intervention program.

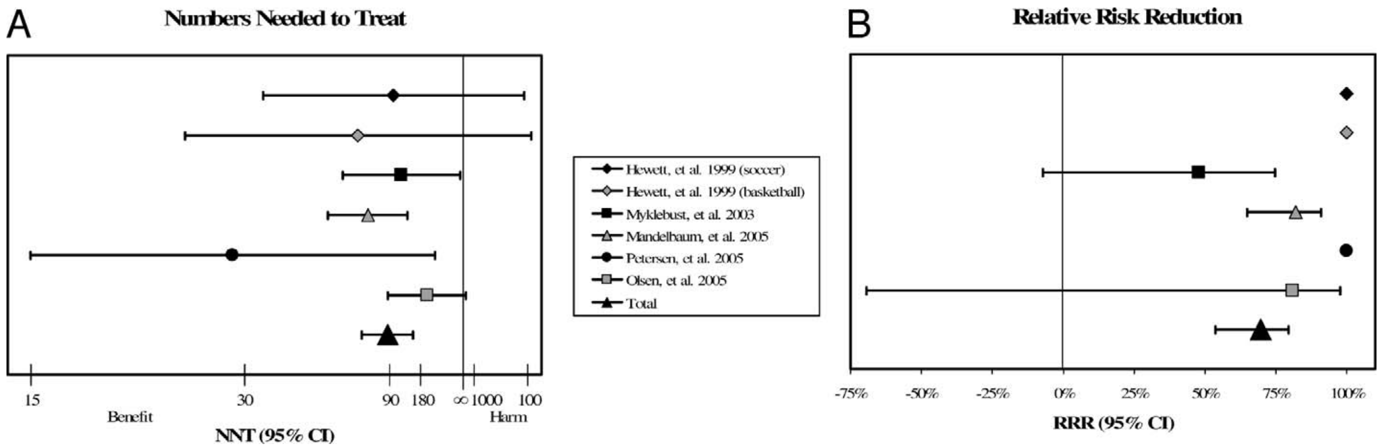
Petersen et al

In this prospective, matched cohort study, investigators evaluated German female handball players over the course of 1 season. Intervention teams were prospectively matched with control teams. The intervention program was performed for 10 minutes before practice, 3 times per week during the preseason and then 1 time per week for the remainder of the season. The program included a 6-phase balance and jump training program. Another component was the educational program to raise awareness of correct exercise technique and common mechanism of injuries. Exposures were defined as exposure to risk during practices or games and were recorded by a coach or the team physiotherapist. Injuries were reported by coaches and evaluated by a physiotherapist and physician, using magnetic resonance imaging and arthroscopic examination when necessary.

No noncontact ACL injuries occurred in the intervention group, compared with 5 in the control group, over the course of the season. An NNT analysis revealed that to prevent 1 noncontact ACL injury over the season, 28 athletes (95% CI = 15 to 250) would have to participate in an intervention program. The RRR was 100% among individuals who participated in the intervention program. Calculations of confidence intervals for RRR were not possible because there were zero injuries in the intervention group.

Olsen et al

The authors of this prospective, cluster randomized control trial examined 15-year-old to 17-year-old female and male handball players. Teams were block randomized to participate in intervention or control groups over the course of an 8-month season. The intervention program was 15 to 20 minutes in duration and included 4 sets of exercises: warm-up, technique, balance, and strength/power (plyometrics). The program was performed before every practice for the first 15 sessions and then once per week for the remainder of the season. Before beginning the program, each team received program de-



A, Numbers needed to treat and 95% confidence intervals. B, Relative risk reduction and 95% confidence intervals.

tails from a Handball Federation instructor. Players were verbally encouraged to perform tasks with correct technique focusing on core, hip, and knee stability and to provide feedback to other players during exercise sessions. Intervention teams were provided with program books, 5 wobble boards, and 5 balance mats. Athlete-exposures and participation in the intervention program were recorded by coaches, who were contacted at least every month by a physiotherapist who collected data for the study. Coaches were responsible for reporting injuries, and injuries were confirmed with physiotherapist interview and sports medicine physician evaluation, with further imaging studies or arthroscopic examination if necessary.

Over the 8-month season, 1 noncontact female ACL injury occurred in the intervention group, and 5 such injuries occurred in the control group. No male noncontact ACL injuries were seen in either group during the study. An NNT analysis showed that to prevent 1 noncontact ACL injury over the course of the season, 193 athletes (95% CI = NNTB 89 to ∞ to NNTH 1177) would have to participate in an intervention program. The RRR for noncontact ACL injury was 81% (95% CI = −69% to 98%) among individuals who participated in the intervention program.

Pooled Results

We pooled the results of individual studies to obtain an overall NNT and RRR. The NNT analysis demonstrated that to prevent 1 noncontact ACL injury over the season, 89 athletes (95% CI = NNTB 66 to 136) would have to participate in an intervention program. The RRR for noncontact ACL injury was 70% (95% CI = 54% to 80%) among individuals who participated in the intervention program.

DISCUSSION

Summary of Results

All of the individual studies demonstrated decreased injury rates among the intervention group compared with the control group (Table 2). Examination of the CIs for the NNT and RRR demonstrated that the results must be interpreted with caution, as some values cross zero (Figure and 2). Pooled results from the 5 studies provide a better estimate of the prophylactic training effect and indicate that neuromuscular training programs reduced the incidence of noncontact ACL injuries.

Limitations of Included Studies

A limitation of all of the studies was the small number of noncontact ACL injuries. Two studies[2,10] described zero noncontact ACL injuries in the intervention group. Two conclusions may be drawn from these data: (1) either the intervention program was 100% effective, or (2) not enough individuals were studied to demonstrate the true effectiveness of the programs. Because noncontact ACL injuries had a relatively low incidence rate (less than 0.24 per 1000 hours of exposure), a large number of individuals would need to be studied to effectively compare the intervention and control groups. Low numbers of injuries and exposures were likely the reason for the wide range of point estimates and CIs among the individual studies. Data from 2 studies[7,9] may have also been influenced by a previous history of knee sprain in participants, which is thought to be a risk factor for future injuries.[34]

Calculation of exposure rates also varied among the included studies. Two common methods used measured event exposures and hours of exposure. Although we can estimate that 1 event exposure was equal to 2 hours, this assumption can severely skew exposure estimates and incidence rates. Another limitation was the method for recording exposure data. Coaches, players, or team medical staff were commonly responsible for recording exposure rate data. This method often leads to estimating exposure rates over the course of a week and does not specifically allow data to be gathered regarding players who may have an increased risk of exposure due to increased playing time.

Another limitation was the combination of training methods used. Most programs used a combination of stretching, strengthening, plyometrics, agility drills, and an educational component aimed at teaching correct exercise techniques and common mechanisms of injuries. Although all the intervention programs were similar, it was difficult to determine if any one aspect was more responsible than others for the decreased noncontact ACL injury rate. Compliance and frequency of program participation also varied among studies, making it difficult to determine the optimal number of training sessions to prevent noncontact ACL injuries.

Lack of randomization was also a limitation, as 2 groups[2,13] allowed teams to choose group allocation and only 1 group[7] truly randomized group assignment. This factor may have biased results and does not account for the types of intervention activities that control teams may have conducted during their usual training regimen.

Finally, only female high school–aged and elite athletes participating in the sports of handball, soccer, and basketball were studied. Generalization to males and other sports and age groups may not be appropriate, and further study is warranted in this area.

Optimal Prevention Program

After analysis and synthesis of the 5 studies,[2,7,9,10,13] we suggest that the optimal injury prevention program be progressive and include aspects of stretching, strengthening, plyometric, and agility exercises. It has been suggested that neuromuscular training programs address risk factors that are present in the athletes participating in a particular sport.[35] Most of the teams were able to integrate sport-specific exercises into their injury prevention program, which may serve as a model for the development of future programs.[7,9,10,13]

A common theme among the programs was the educational component and verbal feedback provided by a certified athletic trainer or sports physical therapist regarding proper exercise technique. Augmented feedback has been shown to decrease peak vertical ground reaction forces from landing more than sensory feedback or no feedback.[36] The effect of feedback from a qualified instructor regarding proper exercise technique may often be underestimated and was likely a large contributor to the success of the injury prevention programs.

Duration and Frequency

Frequency and duration of neuromuscular training programs differed greatly among the studies. Two groups[2,13] used an exclusive preseason or in-season–only program. The preseason-only program was performed for 60 to 90 minutes, 3 times per week, for 6 weeks.[2] The in-season–only program was performed for 20 minutes before each practice session.[13] The other 3 groups[7,9,10] used a program with greater training emphasis in the preseason and only 1 session per week during the season. Each training session was performed for 10 to 20 minutes before practice sessions. Therefore, we suggest that a neuromuscular training program to prevent noncontact ACL injuries be performed for 10 to 20 minutes at least 3 days per week in the preseason and at least 1 time per week during the season.

Mechanism of Effectiveness

Although the exact mechanism of injury prevention program effectiveness remains unknown, risk factors that predispose individuals to noncontact ACL injury have been identified.[27] Minimizing exposure to high-risk positions may decrease noncontact ACL injuries.[27,35,37] Authors of a recent prospective study[27] determined that increased knee abduction angle, increased knee abduction moment, increased peak vertical ground reaction force, and decreased maximal knee flexion angle during landing were associated with noncontact ACL ligament rupture. Decreased neuromuscular control of the hip and knee may place the ACL at risk for rupture.[25] The areas that are thought to be influenced by training programs are landing with correct technique (soft landing with bent knee and knee in alignment with the second toe) and proper deceleration techniques. Education and instruction regarding jumping, running, and cutting maneuvers are also thought to decrease injury risk. Neuromuscular training programs incorporating balance, plyometrics, and strengthening exercises have demonstrated effectiveness in reducing knee valgus measures during landing[25] as well as other known risk factors for noncontact ACL injuries.[23–28]

Performance Enhancement Aspect

Neuromuscular training programs for injury prevention also address factors that have been shown to improve athletic performance. Balance, explosive strength training exercises, and plyometrics improved vertical jump, speed, and agility in numerous studies.[38–43] As a result of the minimal time commitment and the multiple benefits achievable through neuromuscular training programs, it would be prudent for sport coaches, strength and conditioning professionals, certified athletic trainers, and sports physical therapists to implement these dual-benefit programs within the current training programs of high-risk athletes.

Level of Evidence

In spite of the limitations of these studies, the preponderance of evidence supports neuromuscular training programs and their ability to prevent ACL injuries. The studies varied in methodologic quality, but one was a high-quality randomized clinical trial.[7] Given this level of evidence, neuromuscular training can be recommended as an effective method for preventing female noncontact ACL injuries, with a Strength of Recommendation Taxonomy[44] level of recommendation of 1 and strength of recommendation of B.

CONCLUSIONS

Neuromuscular training programs designed to prevent noncontact ACL injuries in females are likely to reduce injuries, but some findings are associated with wide confidence intervals (and some that cross zero) for NNT and RRR estimates. Injury prevention programs and the nature of the protective mechanism should be further researched in more heterogeneous sporting populations. A progressive, sport-specific neuromuscular training program consisting of plyometric, balance, and agility exercises should be performed to aid in preventing noncontact ACL injuries and to improve physical performance.

REFERENCES

1. Miyasaka KC, Daniel DM, Stone ML, Hirshman P. The incidence of knee ligament injuries in the general population. *Am J Knee Surg.* 1991;4:3–8.
2. Hewett TE, Lindenfeld TN, Riccobene JV, Noyes FR. The effect of neuromuscular training on the incidence of knee injury in female athletes: a prospective study. *Am J Sports Med.* 1999;27:699–706.
3. Jomha NM, Borton DC, Clingeleffer AJ, Pinczewski LA. Long-term osteoarthritic changes in anterior cruciate ligament reconstructed knees. *Clin Orthop Relat Res.* 1999;358:188–193.
4. Nebelung W, Wuschech H. Thirty-five years of follow-up of anterior cruciate ligament–deficient knees in high-level athletes. *Arthroscopy.* 2005;21:696–702.
5. Strand T, Molster A, Hordvik M, Krukhaug Y. Long-term follow-up after primary repair of the anterior cruciate ligament: clinical and radiological

evaluation 15–23 years postoperatively. *Arch Orthop Trauma Surg.* 2005;125:217–221.
6. Arendt E, Dick R. Knee injury patterns among men and women in collegiate basketball and soccer. NCAA data and review of literature. *Am J Sports Med.* 1995;23:694–701.
7. Olsen OE, Myklebust G, Engebretsen L, Holme I, Bahr R. Exercises to prevent lower limb injuries in youth sports: cluster randomised controlled trial. *BMJ.* 2005;330:449.
8. Giza E, Mithofer K, Farrell L, Zarins B, Gill T. Injuries in women's professional soccer. *Br J Sports Med.* 2005;39:212–216.
9. Myklebust G, Engebretsen L, Braekken IH, Skjolberg A, Olsen OE, Bahr R. Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons. *Clin J Sport Med.* 2003;13:71–78.
10. Petersen W, Braun C, Bock W, et al. A controlled prospective case control study of a prevention training program in female team handball players: the German experience. *Arch Orthop Trauma Surg.* 2005;125:614–621.
11. Söderman K, Werner S, Pietilä T, Engström B, Alfredson H. Balance board training: prevention of traumatic injuries of the lower extremities in female soccer players? A prospective randomized intervention study. *Knee Surg Sports Traumatol Arthrosc.* 2000;8:356–363.
12. Hutchinson MR, Ireland ML. Knee injuries in female athletes. *Sports Med.* 1995;19:288–302.
13. Mandelbaum BR, Silvers HJ, Watanabe DS, et al. Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: 2-year follow-up. *Am J Sports Med.* 2005;33:1003–1010.
14. Uhorchak JM, Scoville CR, Williams GN, Arciero RA, St. Pierre P, Taylor DC. Risk factors associated with noncontact injury of the anterior cruciate ligament: a prospective four-year evaluation of 859 West Point Cadets. *Am J Sports Med.* 2003;31:831–842.
15. Wojtys EM, Huston LJ, Boynton MD, Spindler KP, Lindenfeld TN. The effect of the menstrual cycle on anterior cruciate ligament injuries in women as determined by hormone levels. *Am J Sports Med.* 2002;30:182–188.
16. Arendt EA, Bershadsky B, Agel J. Periodicity of noncontact anterior cruciate ligament injuries during the menstrual cycle. *J Gend Specif Med.* 2002;5:19–26.
17. Boden BP, Griffin LY, Garrett WE Jr. Etiology and prevention of noncontact ACL injury. *Physician Sportsmed.* 2000;28(4):53–60.
18. McClay Davis I, Ireland ML. ACL research retreat: the gender bias, April 6–7, 2001. Meeting report and abstracts. *Clin Biomech (Bristol, Avon).* 2001;16:937–959.
19. Yu B, McClure SB, Onate JA, Guskiewicz KM, Kirkendall DT, Garrett WE. Age and gender effects on lower extremity kinematics of youth soccer players in a stop-jump task. *Am J Sports Med.* 2005;33:1356–1364.
20. Myklebust G, Maehlum S, Holm I, Bahr R. A prospective cohort study of anterior cruciate ligament injuries in elite Norwegian team handball. *Scand J Med Sci Sports.* 1998;8:149–153.
21. Heidt RS Jr, Sweeterman LM, Carlonas RL, Traub JA, Tekulve FX. Avoidance of soccer injuries with preseason conditioning. *Am J Sports Med.* 2000;28:659–662.
22. Caraffa A, Cerulli G, Projetti M, Aisa G, Rizzo A. Prevention of anterior cruciate ligament injuries in soccer: a prospective controlled study of proprioceptive training. *Knee Surg Sports Traumatol Arthrosc.* 1996;4:19–21.
23. Wilkerson GB, Colston MA, Short NI, Neal KL, Hoewischer PE, Pixley JJ. Neuromuscular changes in female collegiate athletes resulting from a plyometric jump-training program. *J Athl Train.* 2004;39:17–23.
24. Myer GD, Ford KR, Palumbo JP, Hewett TE. Neuromuscular training improves performance and lower-extremity biomechanics in female athletes. *J Strength Cond Res.* 2005;19:51–60.
25. Myer GD, Ford KR, McLean SG, Hewett TE. The effects of plyometric versus dynamic stabilization and balance training on lower extremity biomechanics. *Am J Sports Med.* 2005;34:445–455.
26. Lephart SM, Abt JP, Ferris CM, et al. Neuromuscular and biomechanical characteristic changes in high school athletes: a plyometric versus basic resistance program. *Br J Sports Med.* 2005;39:932–938.
27. Hewett TE, Myer GD, Ford KR, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med.* 2005;33:492–501.
28. Chimera NJ, Swanik KA, Swanik CB, Straub SJ. Effects of plyometric training on muscle-activation strategies and performance in female athletes. *J Athl Train.* 2004;39:24–31.
29. Barratt A, Wyer PC, Hatala R, et al. Tips for learners of evidence-based medicine: 1. Relative risk reduction, absolute risk reduction and number needed to treat. *CMAJ.* 2004;171:353–358.
30. Altman DG. Confidence intervals for the number needed to treat. *BMJ.* 1998;317:1309–1312.
31. Sherrington C, Herbert RD, Maher CG, Moseley AM. PEDro: a database of randomized trials and systematic reviews in physiotherapy. *Man Ther.* 2000;5:223–226.
32. Moseley A, Maher C, Herbert R, Sherrington C. Reliability of a scale for measuring the methodological quality of clinical trials. Available at: http://www.cochrane.org/colloquia/abstracts/rome/romePA30.htm. Accessed November 1, 2005.
33. University of British Columbia. Clinical Significance Calculator. Vancouver, British Columbia, Canada: University of British Columbia. Available at: http://www.healthcare.ubc.ca/calc/clinsig.html. Accessed November 1, 2005.
34. Arnason A, Sigurdsson SB, Gudmundsson A, Holme I, Engebretsen L, Bahr R. Risk factors for injuries in football. *Am J Sports Med.* 2004;32(suppl 1):5S–16S.
35. Myer GD, Ford KR, Hewett TE. Rationale and clinical techniques for anterior cruciate ligament injury prevention among female athletes. *J Athl Train.* 2004;39:352–364.
36. Onate JA, Guskiewicz KM, Sullivan RJ. Augmented feedback reduces jump landing forces. *J Orthop Sports Phys Ther.* 2001;31:511–517.
37. Lloyd DG. Rationale for training programs to reduce anterior cruciate ligament injuries in Australian football. *J Orthop Sports Phys Ther.* 2001;31:645–654.
38. Fatouros IG, Jamurtas AZ, Leontsini D, et al. Evaluation of plyometric exercise training, weight training, and their combination on vertical jumping performance and leg strength. *J Strength Cond Res.* 2000;14:470–476.
39. Luebbers PE, Potteiger JA, Hulver MW, Thyfault JP, Carper MJ, Lockwood RH. Effects of plyometric training and recovery on vertical jump performance and anaerobic power. *J Strength Cond Res.* 2003;17:704–709.
40. Cronin JB, Hansen KT. Strength and power predictors of sports speed. *J Strength Cond Res.* 2005;19:349–357.
41. Siegler J, Gaskill S, Ruby B. Changes evaluated in soccer-specific power endurance either with or without a 10-week, in-season, intermittent, high-intensity training protocol. *J Strength Cond Res.* 2003;17:379–387.
42. Gehri DJ, Ricard MD, Kleiner DM, Kirkendall DT. A comparison of plyometric training techniques for improving vertical jump ability and energy production. *J Strength Cond Res.* 1998;12:85–89.
43. Newton RU, Kraemer WJ, Häkkinen K. Effects of ballistic training on preseason preparation of elite volleyball players. *Med Sci Sports Exerc.* 1999;31:323–330.
44. Ebell MH, Siwek J, Weiss BD, et al. Strength of recommendation taxonomy (SORT): a patient-centered approach to grading evidence in the medical literature. *Am Fam Physician.* 2004;69:548–556.