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Shiren G. Assaly
University of the Pacific

Todd E. Davenport
University of the Pacific, tdavenport@pacific.edu

Katrin Mattern-Baxter
University of the Pacific

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Effectiveness of Neuromuscular Conditioning to Prevent Anterior Cruciate Ligament Injuries in Female Athletes: A Critical Synthesis of Literature

Shiren Assaly, SPT[1]
Todd E. Davenport, PT, DPT, OCS[2]
Katrin Mattern-Baxter, PT, DPT, PCS[2]

[1]*Doctor of Physical Therapy Student, Department of Physical Therapy, Thomas J. Long School of Pharmacy and Health Sciences, University of the Pacific, Stockton, CA*
[2]*Assistant Professor, Department of Physical Therapy, Thomas J. Long School of Pharmacy and Health Sciences, University of the Pacific, Stockton, CA*

ABSTRACT

Background and Purpose: Anterior cruciate ligament (ACL) injuries are common among female athletes. The purpose of this literature review was to assess the effectiveness of neuromuscular conditioning to modify biomechanical risk factors for ACL injury. **Method:** A structured literature search was conducted to identify primary research articles. Articles were graded according to their strength of evidence and a qualitative literature review was completed. **Results:** Seven primary research studies were available for analysis that documented the effects of neuromuscular conditioning (range of evidence grades: 1B-3B). Lower limb kinematics, lower limb kinetics, and incidence of tears were the primary outcomes measures. **Discussion:** The effectiveness of neuromuscular training to modify the theoretical and actual risks for ACL injury is promising but not yet adequately confirmed in the literature. **Clinical Relevance:** Preliminary evidence indicates the effectiveness of neuromuscular training to reduce ACL injury risk, although mechanisms and optimal dosage of exercise remain unclear.

Key Words: anterior cruciate ligament, female, injury, risk factors, biomechanical, neuromuscular training, exercise

BACKGROUND

The anterior cruciate ligament (ACL) is an important stabilizer of the knee and is placed at risk for injury during numerous sports-related activities. Anterior cruciate ligament injuries are more common among female athletes.[1,2] In fact, female athletes are 4 to 6 times more likely to sustain a knee injury compared to male athletes.[1,2] Furthermore, the knee is the most commonly injured joint in the lower extremity, with the ACL being the most affected.[3] Anterior cruciate ligament injuries may require surgery, extensive rehabilitation, and lead to an increased risk of degenerative arthritis.[4] Researchers have identified specific kinetic and kinematic risk factors among female athletes that increase their risk of injury. Studies have been focused on the use of neuromuscular conditioning to modify such biomechanical risks. These neuromuscular conditioning programs involve stretching, strengthening, plyometric, and functional agility exercises that may improve landing techniques, strengthen muscles, and increase overall stability.[4,5]

Multiple intrinsic and extrinsic risk factors differentiate female athletes from the male athletic population, and place them at a higher risk of sustaining an ACL injury. An increased risk of injury has been attributed to anatomical, hormonal, environmental, and biomechanical risk factors.[5] Researchers have identified anatomical differences among females, such as greater pelvic size, smaller ACL size, and larger Q angle, all of which may contribute to an increased risk of injury.[5] In addition, hormonal changes occurring monthly, such as increases in estrogen and relaxin, lead to a decrease in collagen synthesis and contribute to lower tensile properties.[5] Although there are numerous factors that contribute to injury, some biomechanical risk factors may be efficiently addressed, and therefore must become the focus of injury prevention. By understanding that biomechanical risks have the potential to be modified, focus can be placed on the clinical application of neuromuscular conditioning programs to improve certain biomechanical elements.

Biomechanical risks may be attributed to both the kinetics and kinematics of the lower extremity. Numerous biomechanical factors exist among female athletes, such as greater knee extension and valgus during landing, greater hip and knee internal rotation during single-legged landings, and greater quadriceps dependence.[6] Researchers suggest that kinematics within the coronal and sagittal planes may contribute to ACL injury, in particular, decreased knee flexion angles upon foot strike in the sagittal plane and increased knee valgus angles in the coronal plane both play a role in increasing the risk for injury.[7] Furthermore, Imwalle et al[8] found that motions and torques in the coronal plane play a significant role, and suggested that the focus of training must be placed upon controlling motions within this plane. However, it is important to recognize that injury is often due to several motions in multiple planes. Therefore proper training in both the coronal and sagittal planes are necessary to decrease the risk of injury.[8] In addition kinetic risk factors contribute to an increased risk of ACL injury. Researchers suggest that a decrease in knee flexion in conjunction with large quadriceps contraction leads to anterior tibial shear forces that may contribute to ACL ruptures.[9] By understanding the biomechanical elements, the effectiveness of neuromuscular conditioning on the modification of these controllable risk factors may be investigated.

The importance of implementing neuromuscular training programs to modify kinetic and kinematic risks recently has become an intense focus of research.[4,5] Although the interest in ACL injury prevention has expanded in recent years, studies with higher levels of evidence remain minimal. Current evidence shows that neuromuscular training programs can alter biomechanical risk factors, indirectly decrease the potential for injury, and ultimately improve athletic performance.[9] However, researchers have yet to focus on specific neuromuscular training programs and the direct effects they have on ACL injury prevention. Thus, the purpose of this literature review is to assess the biomechanical risk factors associated with ACL injury among female athletes and compare the current literature on the effectiveness of neuromuscular conditioning in the modification of such risks.

METHODS

A literature search for neuromuscular conditioning and the prevention of ACL injuries among female athletes was conducted using the following key words: *anterior cruciate ligament, ACL, athlete, biomechanical risk factors, females, injury, kinematics, kinetics, neuromuscular conditioning, neuromuscular training, prevention,* and *risk factors*. The search was conducted in the following databases: Academic Search Complete, CINAHL, Cochrane Library, PubMed, SCOPUS, and SPORTDiscus. Only primary research studies that were published in peer-reviewed journals, written in the English language, and studied female athletes were included in this review (Table 1).

Sackett's levels of evidence were determined for each research study in order to establish their methodological quality (Table 2).[10] Using a number and letter scale from 1A being the strongest and most reliable, to 5 being the least reliable, each study was rated on this scale.[10] One study was rated at level 1B,[4] one study at level 2B,[5] and 5 studies at level 3B.[6,7,11,12,13] Subsequently, each study was assessed critically with focus placed upon key interventions, patient populations, outcomes measures, and significant results (Table 3).

Table 1. Description of Searches for Studies Conducted on Neuromuscular Conditioning for Anterior Cruciate Ligament Injury Prevention in Female Athletes

Name of Article	Academic Search Complete	CINAHL	Cochrane Library	PubMed	SCOPUS	SPORT Discus
Date of Search	December 5, 2010	December 4, 2010	December 5, 2010	December 3, 2010	December 2, 2010	December 5, 2010
Total no. articles found	28	21	24	18	51	29
No. articles appropriate for review	4	4	4	2	5	2
Chappell and Limpisvasti[7]	X	X			X	
Gilchrist et al[4]	X	X	X	X		
Mandelbaum et al[5]	X	X			X	
Lim et al[6]			X			
Myer et al[11]			X		X	
Myer et al[12]			X		X	X
Zebis et al[13]	X	X		X	X	X

Table 2. Operational Definitions for Levels of Evidence[10]

Level of Evidence	Description
1A	Systematic review of randomized controlled trials (RCT)
1B	RCTs with narrow confidence intervals
1C	All or none case series
2A	Systematic review cohort studies
2B	Cohort study/low quality RCT
2C	Outcomes research
3A	Systematic review of case controlled studies
3B	Case-controlled study
4	Case series, poor cohort case controlled
5	Expert opinion

RESULTS

A total of 7 studies were found on neuromuscular conditioning and ACL injury prevention among female athletes. Although particular publication years were not specified in the search parameters, the studies reviewed were published between 2005 and 2009. Of these, one was a randomized control trial,[4] one was a cohort study,[5] and 5 were controlled laboratory studies.[6,7,11,12,13]

Neuromuscular Conditioning and Modification of Coronal and Sagittal Plane Kinematics

Four studies examined the effects of neuromuscular conditioning on the modification of coronal and sagittal plane kinematics, with the emphasis placed on the reduction of ACL injuries through the modification of biomechanical risk factors.

In a randomized controlled trial, Chappell and Limpisvasti,[7] compared the kinetics and kinematics of 33 NCAA Division I female collegiate athletes before and after undergoing a neuromuscular training program.[7] The athletes underwent a 10 to 15 minute program that incorporated core strengthening, dynamic stability, jump training, and plyometric exercises 6 days a week for 6 weeks.[7] Following intervention, results showed a significant increase in knee flexion angles upon foot strike (p = .003) and maximum knee flexion angles during stance phase (p = .006). In addition, there was a decrease in maximum dynamic knee valgus (p = .04).[7] The work conducted by Chappell and Limpisvasti[7] recognized the importance of neuromuscular training in the modification of risk factors and supported the position that neuromuscular training aids in the prevention of ACL injuries among female athletes.

In a subsequent study by Lim et al,[6] the focus of the intervention was placed on proper biomechanics and the modification

Table 3. Description and Outcomes of Studies Evaluating Neuromuscular Conditioning for Anterior Cruciate Ligament Injury Prevention in Female Athletes

Study	Type of Study	Sackett Level of Evidenc[12]	Frequency, Duration, Conditions	Patient Population
Chappell & Limpisvasti[7]	Controlled Laboratory Study	3B	6 times/wk for 6 wks, 10 exercises performed in 10-15 min, prevention program included core strengthening, dynamic joint stability and balance training, jump training, and plyometrics	30 female NCAA Division I athletes: 12 basketball athletes, 18 soccer athletes, with no history of knee injuries. Mean age 19 ± 1.2 yrs Mean height 174 ± 8.5 cm, Mean wt 69.8 ± 10.9 kg
Gilchrist et al[4]	Randomized control trial	1B	3 times/wk for 12 wks PEP* Program, included stretching, strengthening, plyometrics, agilities, and avoidance of high-risk positions	61 NCAA Division I women's soccer teams: 26 intervention teams (583 athletes), 35 control teams (852 athletes)
Lim et al[6]	Controlled Laboratory Study	3B	20 min during regular team basketball practice for 8 wks, 6 part SIPTP†	22 high school female basketball players, 2 teams: 11 intervention athletes, 11 control athletes, with no history of lower extremity injuries, Mean height 171.3 ± 6.9 cm, Mean body mass 63.9 ± 5.3 kg, Mean age 17.1 ± 1.1 yrs
Mandelbaum et al[5]	Cohort Study	2B	20 min PEP program during team practice for 1 yr, included stretching, strengthening, plyometric, and agility exercises. Resources included an instructional warm-up videotape and literature packet	Year 1- 52 intervention teams (1041 athletes), 95 control teams (1905 athletes). Year 2- 45 intervention teams (844 athletes), 112 control teams (1913 athletes). Ages 14-18. All female soccer teams in the Coast Soccer League of Southern California
Myer et al[11]	Controlled Laboratory Study	3B	3 times/wk for 7 wks of a neuromuscular training program	29 high school female soccer and basketball athletes: 18 intervention athletes, 11 control athletes, n intervention group: mean height and body mass 165.5 ± 6.5 cm 64.6 ± 10.4 kg In control group- mean ht and body mass168.9 ± 9.1 cm and 64.0 ± 7.9 kg
Myer et al[12]	Controlled Laboratory Study	3B	90 min plyometric or dynamic stabilization program for 18 sessions in 7 wks	18 high school volleyball female athletes, 8 subjects in plyometric group, 10 subjects in balance group Mean age for both groups 15.90 ± .8 yrs In plyometric group: initial height 169.5 ± 6.1 cm, and body mass 61.4 ± 7.3 kg In balance group: initial height 168.0 ± 7.3 cm, body mass 66.4 ±11.8 kg
Zebis et al[13]	Controlled Laboratory Study	3B	6 months of regular training as control group. Followed by 20 min, 2 times/wk for 18 wks of a neuromuscular training program with 6 levels, each level performed 2x/wk for 3 wks before progressing to the next level	20 female athletes: 12 elite soccer players, 8 elite handball players, 2 teams Age 26 ± 3 yr, Height 174 ± 6 cm, Wt 70 ± 9 kg

*** Prevent injury and Enhance Performance (PEP) Program[4] consists of warm-up, stretching, strengthening, plyometrics, and sport specific agility exercises.**
† Sports injury prevention training program (SIPTP)[6] is composed of 6 parts (warm-up, stretching, strengthening, plyometrics, agility and alternative exercise–warm down).

Important Outcome Measures	Important Results
3-dimensional motion analysis, force plate data, vertical jump and hop tests, 1 drop jump, 1 vertical stop jump	Neuromuscular training program modified movement patterns by increasing knee flexion during stance phase of drop jump but not stop jump, and decreasing dynamic knee valgus moment during stance phase of stop jump but not drop jump.
Weekly participation and injury reports, observational and written surveys	PEP Program was effective at preventing ACL injuries. Results showed a 70% decrease in non-contact ACL injuries in intervention groups. The overall ACL injury rate among intervention athletes was 1.7 times less than control athletes.
Rebound-jump task using motion analysis measurements, video graphic and analog data, EMG data	Neuromuscular training may alter kinematic risks associated with ACL injuries. Results showed an increase in strength and flexibility. Greater knee flexion angles and maximum knee abduction torques were observed in the experimental group.
Weekly injury report form, knee injury questionnaire, confirmation of a non-contact ACL tear included a history, physical, MRI or arthroscopic procedure	Significant results showed that the use of a neuromuscular training program may have a direct benefit in reducing ACL injuries. Results from year 1 indicated an 88% overall reduction of ACL injury per athlete. Results following year 2 showed a 74% reduction in ACL injuries in the intervention group.
Drop vertical jump using 3-dimensional motion analysis testing, video cameras, and force platforms	Following neuromuscular training, significant reductions observed among "high-risk" females regarding risk factors to ACL injury. High risk athletes attained a 13% decrease in peak knee abduction torques, while no significant effects shown among low risk femaleathletes.Results also showed knee abduction moments among high risk athletes had not reduced to the same level as low risk athletes.
3-dimensional lower limb joint kinematics testing with force platforms to evaluate drop vertical jump and single legged medial drop landing tasks	Significant reductions in knee valgus moments in both the plyometric and balance training groups. Both protocols decreased hip adduction angles during medial drop landing. Plyometric training significantly increased knee flexion upon initial contact during drop vertical jump. Both plyometric and balance training showed similar effects on the kinematics within the coronal plane. However, only plyometric training produced positive effects in the sagittal plane.
EMG analysis during side cutting maneuver with force plates, goniometric measurements	Significant increase in activity of the semitendinosus muscle following neuromuscular training. Program altered the neuromuscular activation patterns of the medial hamstring during side cutting without altering the activity patterns of the quadriceps, thereby decreasing anterior tibial shearing associated with ACL injury.

of coronal and sagittal plane motions. The study examined the effectiveness of a neuromuscular training program on increasing the flexibility and strength of female athletes in order to improve biomechanical properties related to ACL injury.[6] Subjects included 22 high school female athletes in either a control or intervention group.[6] During the 8-week training period, the intervention group underwent a 6-part prevention program that involved warm-up, stretching, strengthening, plyometrics, and agility.[6] Results were obtained through the use of pre- and posttraining motion analysis measurements. The experimental group showed an increase in strength (p = .004 to .04) and an increase in flexibility (p = .022).[6] The female athletes also exhibited greater knee flexion angles (p = .023) and maximum knee abduction torques (p = .043),[6] whereas, the control group showed no statistical differences between pre- and posttraining for any of the parameters tested (p = .084 to .873).[6] The necessity of incorporating a neuromuscular training program was confirmed through the modification of biomechanical risk factors. However, a limitation included the assumption of a cause-effect relationship.[6] Researchers did not study the direct effects of the specific neuromuscular conditioning program on the reduction of ACL injury. Instead, the focus of the study, much like many other studies, was to assess the effects of a training program on biomechanical risk factors. Consequently, the study involves a relatively low level of evidence and therefore the information provided may not be considered highly reliable or generalizable.

In a controlled laboratory study, Myer et al[12] found that female athletes displayed an increase in knee valgus in the coronal plane and a decrease in knee flexion in the sagittal plane when compared to male athletes during landing and pivoting maneuvers. The authors examined how improving lower extremity kinematics would contribute to decreased sagittal plane motion and increased coronal plane motion, and ultimately reduce the risk of injury.[12] The researchers compared the effects of plyometric jumping and dynamic stabilization during landing, and assessed the contributions to coronal and sagittal plane motions linked to an increased risk of ACL injury.[12] Eighteen high school female athletes participated in the study, with half of the subjects undergoing a 90-minute plyometric training program for 12 to 18 sessions, and the other half undergoing a dynamic stabilization program.[12] Data was collected using 3-dimensional lower limb joint kinematics testing.[12] The results showed that both the plyometric and balance training protocols decreased hip adduction angles.[12] These results confirmed that neuromuscular training improved coronal plane kinematics and indirectly reduced the risk of ACL injury. In addition, the results showed that athletes in the plyometric training group increased knee flexion upon initial contact ($p = .047$) while there was no effect on athletes in the balance training group.[12] Although plyometric and balance training showed similar effects on the kinematics within the coronal plane, only plyometric training produced positive effects in the sagittal plane.[12] These results indicate that certain neuromuscular training techniques may not be as effective at modifying biomechanical risk factors as was previously believed.

Myer et al[11] focused on the identification of female athletes at high risk of sustaining an injury primarily due to knee abduction moments > 25.5 Nm, and assessed whether a neuromuscular training program could effectively minimize those risks. Knee kinematics were measured using the drop vertical jump (DVJ) test.[11] The controlled laboratory study concluded that 16 female athletes were at high risk (knee abduction moment > 25.5 Nm) and 13 were at low risk (knee abduction moment < 25.5 Nm).[11] Athletes in the intervention group participated in a neuromuscular training program 3 days a week for 7 weeks. Results indicated that the prevention program did modify biomechanical risks factors associated with coronal plane kinematics, but did not show the high percentage of modifications that was expected.[11] Data showed that high risk athletes attained a 13% decrease in their peak knee abduction torques, with no significant effects shown among low risk female athletes.[11] Researchers also found that knee abduction moments among high risk athletes were not reduced to the same level as the low risk athletes.[11] Although Myer and his colleagues recognized a decrease in biomechanical risk factors, they were not able to show that training effectively reduced knee abduction to a low risk level. In addition, neuromuscular training did not show significant changes, leading to uncertainty when implementing prevention programs for all female athletes.

Given that the 4 studies on the effects of neuromuscular training and the modification of coronal and sagittal plane kinematics were rated with lower levels of evidence, conclusions have to be made with caution. Three of the studies[6,7,12] supported the use of neuromuscular training to alter kinematics within the sagittal and coronal plane, while one study[11] disputed the magnitude of the effects on the modification of risk factors and the ultimate prevention of ACL injury. Additionally, by specifically assessing plyometric and balance training, one study[12] showed that not all types of neuromuscular training were equally effective at altering both coronal and sagittal kinematics. Although it appears that neuromuscular training is effective at reducing the risk of ACL injury among female athletes, further research is required to determine specific types of training for these athletes.

Neuromuscular Conditioning and Kinetic Modifications

In a controlled laboratory study, Zebis et al[13] assessed the effects of neuromuscular training on kinetic modifications. The importance of neural activation patterns between the hamstring and quadriceps muscles was addressed. Twenty female athletes underwent neuromuscular training following 6 months of regular training as the control group.[13] All athletes participated in a 20-minute training program 2 times a week for 18 weeks.[13] The program consisted of 6 levels, each of which were performed 2 times a week for 3 weeks before moving on to the next level.[13] The exercises focused on improving neuromuscular control during standing, running, jumping, cutting, and landing tasks.[13] Researchers found that activity in the semitendinosus muscle was significantly increased following neuromuscular training ($p < .01$) and that activity onset of the semitendinosus increased before foot strike ($p < .05$) compared to activity prior to training.[13] In addition, the training altered the neuromuscular activation patterns of the medial hamstring during side cutting without altering the activity patterns of the quadriceps.[13] The significance of hamstring to quadriceps synergy highlighted the potential for injury when hamstring activation ineffectively counteracted eccentric quadriceps forces. To further confirm the positive effects of training on the reduction of ACL injury, the researchers noted that no ACL injuries occurred among the subjects during the neuromuscular training season in comparison to two ACL injuries during the 6-month control season.[13] When compared to no training; it is evident that prevention programs can modify kinetic risk factors. However, it must be noted that the poor synchronization of data between kinetic and kinematic factors within the studies limits the validity of the findings. The researchers focused on kinetic factors with regards to the sagittal plane and not the coronal plane, while kinematic data was addressed with regards to the coronal plane. Without combined analysis of the kinetic and kinematic findings in both planes, it is difficult to draw conclusions on the effectiveness of training.

Given this study on the modification of kinetic factors, limited conclusions may be formulated regarding the importance of conditioning. Due to the relatively low level of evidence, more studies are required to independently verify the effectiveness of neuromuscular conditioning on the modification of kinetic factors in all planes.

Clinical Effects of Neuromuscular Training Programs

In two studies, researchers examined the overall effects of neuromuscular training programs on the incidence of ACL injuries among female athletes. The training programs involved a combination of stretching, strengthening, plyometric, and agility exercises.

In a randomized control trial by Gilchrist et al,[4] a neuromuscular training program was developed to reduce the risk of noncontact ACL injuries among female athletes. The study included 1435 female collegiate soccer athletes on NCAA Division I teams.[4] There were 35 control teams and 26 intervention teams that underwent a 12-week training program involving stretching, strengthening, plyometric, and agility exercises.[4] The findings showed a 70% decrease in noncontact ACL injuries in the intervention group compared to the control group.[4] In addition, the intervention group suffered no ACL injuries in the second half of the season while the control group encountered ACL injuries (0.000 injuries in intervention group vs. 0.249 injuries in control group; $p = .025$).[4] This study confirmed the positive impact neuromuscular training programs may have on the prevention of ACL injuries among female athletes. Limitations of the trial included lack of specificity in exercises performed by the control group and the inability to supervise all intervention groups to ensure adherence to the program.

In a subsequent study, Mandelbaum et

al[5] examined the effects of prevention programs over a two-year period. The purpose of the nonrandomized cohort study was to determine whether a neuromuscular and proprioceptive training program decreased the incidence of ACL injuries among female soccer players. The study was conducted over a 2-year period with different intervention and control groups each year.[5] During year one, 1041 high school female soccer athletes were enrolled in the prevention program, and 1905 female athletes were in the control group.[5] During year two, 844 high school female athletes were enrolled in the prevention program, and 1913 female athletes were in the control group.[5] The intervention group underwent a 20-minute neuromuscular training program during every team practice for one year.[5] The program consisted of stretching, strengthening, plyometric, and agility exercises while the control group continued a regular warm-up program.[5] In year one, the trial indicated an 88% overall reduction of ACL injury per athlete compared to the control group.[5] In year two, the results showed a 74% reduction in ACL injuries in the intervention group compared to the control group.[5] Mandelbaum et al concluded that neuromuscular conditioning programs were effective at reducing the risk of ACL injury and, in addition, had positive effects when used over an extended period of time. It must be noted that this study was limited by lack of randomization.

These studies suggest neuromuscular conditioning can reduce the incidence of ACL tears in female athletes. Because relatively strong levels of evidence characterized both studies, more confident conclusions may be made regarding the efficacy of neuromuscular training on the reduction of ACL injury.

DISCUSSION

The 7 studies presented in this paper investigated the importance of neuromuscular conditioning in the modification of kinetic and kinematic risks. Although research on the subject is still developing, the results from these studies show some promising outcomes for neuromuscular training and the modification of biomechanical risk factors associated with ACL injury.

Four studies[6,7,11,12] assessed the effects of neuromuscular conditioning on the modification of kinematic risk factors. The evidence indicated the importance of neuromuscular training on risk modification within the coronal and sagittal planes. Three of the studies supported the positive effects of neuromuscular training,[6,7,12] while one study[11] disputed the significance of the effects. Additionally, one study[12] found that not all types of neuromuscular training are equally effective at altering coronal and sagittal kinematics. Although the overall data supported the use of neuromuscular conditioning on the modification of kinematic risks, further research is required to determine valuable types of training exercises and their level of effectiveness.

One study[13] assessed the effects of neuromuscular training on kinetic factors linked with an increased risk of ACL injury. Evidence strongly supported the use of neuromuscular conditioning and found that after training, there was an increase in hamstring activity as well as modification in the neuromuscular activation pattern. Because this study focused on the sagittal plane only, further research is required to confidently affirm the effectiveness of neuromuscular conditioning on the modification of kinetic factors in all planes.

Two studies[4,5] with higher levels of evidence examined the effects of neuromuscular training programs on the reduction of ACL injuries among female athletes. These studies validated the importance of neuromuscular training in the reduction of ACL injuries. While both studies confirmed the effectiveness of training programs, one study[5] found additional positive effects of training over an extended period of time.

CONCLUSION

The purpose of this literature review was to assess the biomechanical risk factors associated with ACL injury and evaluate current literature on the effectiveness of neuromuscular conditioning in the modification of such risks. Research analysis on kinetic and kinematic factors provided evidence in support of neuromuscular conditioning and the modification of risk factors. Overall, it may be concluded that neuromuscular conditioning modifies biomechanical risk factors and indirectly reduces the risk for ACL injury among female athletes. Although focus has been placed on the use of neuromuscular conditioning to modify risks, little research is available on the direct effects of specific neuromuscular training programs. As research on the subject continues to evolve, emphasis must be placed on the assessment of specific neuromuscular training programs and ACL injury prevention. Furthermore, current research provides information regarding the use of neuromuscular conditioning for female athletes at risk of sustaining an injury. However, studies with stronger levels of evidence must be conducted to further determine the effects of neuromuscular conditioning on the modification of risk factors and the reduction of ACL injury among female athletes.

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INVITED COMMENTARY: FINDING COMMON GROUND

(continued from page 132)

democratic input on terminology" with international acceptance.[4] This committee consisted of 20 members from 16 countries. The committee worked for 10 years to build consensus of terminology that would clarify anatomical terms and allow for better communication between speakers of many languages. In 1998 the committee published *TerminologiaAnatomica*[5] (TA), creating a lexicon that transformed the original Latin into terms based on English– the new language of science. There were also fundamental changes to some of the basic Latin terms that had been used for years. Most significantly, they changed much of the language many of us struggled to learn and have come to know so well.

TerminologiaAnatomica was published internationally but received only limited exposure among medical practitioners. While text books quickly adopted the new terminology, educators have been inconsistent in applying the new standards in instruction. Some anatomy curricula have adopted only subsets of the terms[3,6] and thus regional differences have cropped up within North America. Journals were slow to adopt the terminology, most likely due to lack of knowledge of the change. Eventually journals supported the changes through editorials[7] and adopted the changes through their editorial processes. Implementing these changes has been a slow and confusing process for many. This is certainly true for the clinical instructor or clinician who has graduated and has been practicing for over 10 years. These experienced and knowledgeable clinicians work with current students and recently graduated/licensed Physical Therapists who have learned new terminology such as the *fibularis brevis* as opposed to the *peroneus brevis*.

It has been 12 years (1999) since the last updated publication on anatomy terminology and there is still a lack of adoption of the new terms. The authors of one study in 2008[3] stated that they "highly recommend" following the last revision of the TA in any educational, scientific, translating, editing, revising and publishing activities." As an anatomy instructor (within a physical therapy program at a major medical center) who has embraced the international committee's recommendations, I add my enthusiastic support for fully adopting the new TA. To achieve success, we must increase awareness of the new standards through media beyond just the anatomical literature. Table 1 briefly lists some of the changes that directly relate to physical therapy. Adopting the changes in this table is a small but important first step toward broader change that will improve communication between all medical professionals, both in the research and clinic settings.

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