Effectiveness of a Neuromuscular and Proprioceptive Training Program in Preventing the Incidence of Anterior Cruciate Ligament Injuries in Female Athletes

2-Year Follow-up

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Background: Anterior cruciate ligament disruption has been problematic in recreational and competitive athletes. These injuries can lead to an inability to perform athletically and initiate degenerative changes at the joint level. Several prevalent studies have indicated that the number of female athletes incurring a serious anterior cruciate ligament injury exceeds that of male counterparts by 2 to 8 times. However, among female athletes, it has not been established whether a neuromuscular and proprioceptive sports-specific training program will consistently reduce the incidence of anterior cruciate ligament injuries.

Purpose: To determine whether a neuromuscular and proprioceptive performance program was effective in decreasing the incidence of anterior cruciate ligament injury within a select population of competitive female youth soccer players.

Methods: In 2000, 1041 female subjects from 52 teams received a sports-specific training intervention in a prospective nonrandomized trial. The control group consisted of the remaining 1905 female soccer players from 95 teams participating in the same league who were age and skill matched. In the 2001 season, 844 female athletes from 45 teams were enrolled in the study, with 1913 female athletes (from 112 teams) serving as the age- and skill-matched control. All subjects were female soccer players between the ages of 14 and 18 and participated in either their traditional warm-up or a sports-specific training intervention before athletic activity over a 2-year period. The intervention consisted of education, stretching, strengthening, plyometrics, and sports-specific agility drills designed to replace the traditional warm-up.

Results: During the 2000 season, there was an 88% decrease in anterior cruciate ligament injury in the enrolled subjects compared to the control group. In year 2 , during the 2001 season, there was a 74% reduction in anterior cruciate ligament tears in the intervention group compared to the age- and skill-matched controls.

Conclusion: Using a neuromuscular training program may have a direct benefit in decreasing the number of anterior cruciate ligament injuries in female soccer players.

Keywords: anterior cruciate ligament (ACL); prevention; soccer

Anterior cruciate ligament disruption has been increasingly problematic in the lives of both recreational and competitive athletes, both physically and psychologically. These injuries can lead to an inability to perform athletically, in addition to initiating degenerative changes at the joint level. In 1972, Title IX of the Educational Amendments was passed to enable women to participate in academic and athletic events without gender discrimination. Since that time, more than 2.36 million girls have participated in high school sports, compared to 300 000 in

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1972.[1] In addition to the increase in women's participation in sports, the incidence of noncontact ACL injuries has increased. Competitive team sports including soccer, basketball, and volleyball are known to require lower extremity dynamic stability to withstand the demands of cutting, decelerating, and jumping. Several prevalent studies have indicated that the number of female athletes incurring noncontact ACL injuries exceeds their male counterparts by 2 to 8 times, which would indicate a level of gender specificity.[1,12,21,26] Complete ACL rupture has been very closely associated with knee instability and secondary disruption of the menisci and chondral surfaces, as well as the onset of osteoarthritis. Lohmander et al[25] described the biochemical response to an acute ACL and meniscal injury and the subsequent increase in the concentration of aggrecan fragments found intra-articularly. The presence of cartilage oligomeric matrix protein, c-propeptide of type II collagen, bone sialoprotein, matrix metalloproteinases 1 and 3, stromelysin, and tissue inhibitor of metalloproteinases 1 adds more direct evidence of cartilage catabolism and turnover after acute knee injury. These initial biochemical responses after an articular cartilage injury lead to progressive chondropenia and the ultimate degenerative consequence of osteoarthritis.[24,25]

The purpose of this study was to determine whether a neuromuscular and proprioceptive performance program was effective in decreasing the incidence of ACL injury among competitive female youth soccer players in a Southern California soccer league.

MATERIALS AND METHODS

Subjects

A total of 1041 female subjects (from 52 teams) between the ages of 14 and 18 years participated in the first year of this nonrandomized prospective 2-year study. The control group consisted of the remaining 1905 female soccer players (from 95 teams) participating in the same league (age and skill matched). In year 2 of the study (2001 season), 844 female athletes (from 45 teams) were enrolled in the study. The remaining 1913 female athletes (from 112 teams) served as the nonrandomized, age- and skill-matched control group.

All of the female soccer teams (14-18 years of age) within the Coast Soccer League of Southern California were contacted via central Web site posting and e-mail solicitation and queried about interest in a new soccer training program. Fifty-two (2000) and 45 (2001) of the teams, respectively, that expressed interest were invited to participate in the program. The remaining teams participating in the league served as the age- and skill-matched control group. Internal review board approval was granted by the Human Subjects Committee from St John's Hospital, Santa Monica, California.

Instructional Methods

Each team was mailed an educational videotape depicting the 20-minute warm-up program and a supplemental literature packet (see Table 1). In addition, each coach attended a mandatory league meeting in which the Prevent Injury and Enhance Performance (PEP) Program was introduced and the parameters were described. The instructional videotape was designed to serve as an educational tool and to directly replace the traditional warm-up being performed by the athletes previously. In the videotape, female members of the US Olympic Development Program served as the models to demonstrate the therapeutic exercises. The videotape consisted of education and 3 basic warm-up activities, 5 stretching techniques for the trunk and lower extremity, 3 strengthening exercises, 5 plyometric activities, and 3 soccer-specific agility drills. The videotape demonstrated how to perform each activity with proper biomechanical technique. The literature packet consisted of detailed information regarding each specific exercise, a sample field set up to improve the time efficiency for each coach, a contact sheet with the project coordinator's phone number, and e-mail and fax information. Distance covered and the numbers of repetitions for each exercise were clearly outlined in the videotape and the supplemental literature handout. Throughout the videotape, there is a heavy emphasis on proper technique: landing technique, stressing "soft landing" and deep hip and knee flexion as opposed to landing with a "flat foot" in lower extremity extension. Visual examples of proper and improper biomechanical performance were given for each individual exercise via the educational videotape. Each subject participating in the research study was required to view the videotape. The control group performed a warm-up designed by their individual coach.

Athlete Exposure

Athletic exposure was defined as participation in any practice or game in which an athlete was exposed to the possibility of an athletic injury. Exposure was monitored via the coach on a weekly exposure reporting form. This form was e-mailed or faxed to the project coordinator. If a player did not participate in a training session or a game, the coach was instructed to note the reason for that player's absence. If any information was missing, a member of the research team contacted the coach for further follow-up.

Injury Reporting

Injuries were reported by the coach on a weekly injury report form to the project coordinator via e-mail or fax. The coach was asked to designate the location of injury, the cause of injury, the type of injury, the severity of the injury, and whether subsequent medical follow-up was sought out by the injured subject. If a knee injury occurred, the player was given a knee injury questionnaire to complete within 10 days of the initial injury. This form asked specific information regarding the type of knee injury (muscular, meniscus, ligament, tendon, or contusion), history of knee injury, duration of injury, and diagnosis of injury. This form was returned to the project coordinator for follow-up. If the questionnaire was not returned within 10 days of the date of injury, the project coordinator contacted the coach to urge the player to complete the required paperwork

TABLE 1
Prevent Injury and Enhance Performance Program[a]

Exercise	Distance	Repetitions
1. Warm-up		
Jog line to line	50 yd	1
Shuttle run	50 yd	1
Backward running	50 yd	1
2. Stretching		
Calf stretch	NA	2 × 30 s
Quadriceps stretch	NA	2 × 30 s
Hamstring stretch	NA	2 × 30 s
Inner thigh stretch	NA	2 × 30 s
Hip flexor stretch	NA	2 × 30 s
3. Strengthening		
Walking lunges	20 yd	2 passes
Russian hamstring	NA	30
Single-toe raises	NA	30, bilaterally
4. Plyometrics		
Lateral hops	2- to 6-in cone	20
Forward hops	2- to 6-in cone	20
Single-leg hops	2- to 6-in cone	20
Vertical jumps	NA	20
Scissors jumps	NA	20
5. Agilities		
Shuttle run	40 yd	1
Diagonal run	40 yd	1
Bounding run	45-50 yd	1

[a]NA, not applicable.

promptly. This particular study focused on noncontact ACL injuries strictly, as regimented reporting from the control group was not consistent enough to draw a significant comparison regarding other injuries. In addition, because weekly injury reporting is mandatory within the Coast Soccer League, the project coordinator was able to compare the number of noncontact ACL injuries with the league's database to confirm that all injuries within the control group and the intervention were captured.

Quality Assurance

To address quality assurance, a compliance form was administered to each team participating in the program. The form consisted of a checklist depicting each individual component of the program. The coach was asked to observe the team completing the performance of the PEP Program in the last week of the season. The forms were then returned via mail or e-mail to the project coordinator for assessment. Among the 52 and 45 compliance forms distributed in the 2000 and 2001 seasons, respectively, 50 and 45 forms were respectively returned (96.15% vs 100%) from the intervention groups.

Diagnosis

The clinical criteria for confirming a noncontact ACL tear included history, physical examination by a physician, and confirmation via MRI and/or arthroscopic procedure. Copies of a positive MRI result report and a physician's report were obtained for each noncontact ACL injury reported. Only noncontact ACL injuries were included in the statistical analysis.

RESULTS

Statistical analysis of the results was performed using the SAS system, version 8.2 (SAS Institute Inc, Cary, NC). Data were summarized by forming a 2 × 2 table of training intervention by ACL injury for each year. Incidence rates were calculated by 3 different methods. These included the number of ACL injury cases divided by the total number of athlete exposures, the number of ACL injury cases divided by the total number of players, and the number of ACL injury cases divided by the total number of teams. In all 3 cases, overall incidence rate estimates for the 2001 and 2002 reasons combined were calculated similarly. The χ^2 or Fisher exact test was used to calculate proportional differences between the 2 groups: those who received the training intervention and those who did not (control). The Fisher exact test was used rather than the χ^2 test in cases in which the 2 × 2 cells had fewer sample sizes. Relative risk was calculated as the ratio of incidence rates for trained versus untrained. A 95% confidence interval (CI) for relative risk was calculated. The CIs were 2-sided. Statistical significance was set at $P < .05$.

The total number of athlete exposures was calculated, in which an exposure was defined as any practice or game in which an athlete was exposed to the possibility of an athletic injury. In the 2000 soccer season, there were 37 476 exposures for the trained group and 68 580 for the untrained group. A total of 2 ACL tears confirmed by MRI were reported for the intervention group for an incidence rate of 0.05 ACL injuries/athlete/1000 exposures. Thirty-two ACL tears were reported for the control group, resulting in an incidence rate of 0.47 ACL injuries/athlete/1000 exposures (Table 2). These results indicated an 88% overall reduction of ACL injury per individual athlete compared to a skill- and age-matched control athlete. When these results were analyzed using the player as a unit of analysis, the injury incidence for the intervention group was 1.9/1000 players compared to 16.8/1000 players in the control group. The resultant rate ratio was equivalent to 0.11, which was statistically significant at $P = .0001$ (95% CI, 0.03-0.48) (see Table 3). Using the team as a unit of analysis, the injury incidence for the intervention group was 0.04/100 teams compared to 0.37/100 teams for the control group. The resultant rate ratio was equivalent to 0.11, which was statistically significant at $P = .0003$ (95% CI, 0.03-0.49) (see Table 4).

In year 2 (2001) of the study, the total number of athlete exposures was 30 384 for the trained group and 68 868 for the untrained group. Four ACL tears were reported in the intervention group, with an incidence rate of 0.13 injuries/athlete/1000 exposures. Thirty-five ACL tears were reported in the control group, with an incidence rate of 0.51 injuries/athlete/1000 exposures. This rate corresponds to an overall 74% reduction in ACL tears in the

TABLE 2
Incidence Rate and Relative Risk of ACL Tears by Total Number of Exposures, 2000 and 2001

	Total No. Exposures	No. ACL Tears	Incidence Rate[a]	Relative Risk	P
Year 1: 2000					
Trained	37 476	2	0.05	0.114	.0001
Untrained	68 580	32	0.47		
Total	106 056	34			
Year 2: 2001					
Trained	30 384	4	0.13	0.259	.0047
Untrained	68 868	35	0.51		
Total	99 252	39			
Overall: 2001 and 2002 combined					
Trained	67 860	6	0.09	0.181	<.0001
Untrained	137 448	67	0.49		
Total	205 308	73			

[a]Rate based on injuries per 1000 athlete exposures.

TABLE 3
Incidence Rate and Relative Risk of ACL Tears by Player, 2000 and 2001

	No. Subjects	No. ACL Tears	Resultant Rate per Player[a]	Relative Risk	P
Year 1: 2000					
Trained	1041	2	1.9	0.114	.0001
Untrained	1905	32	16.8		
Total	2943	34			
Year 2: 2001					
Trained	844	4	4.74	0.259	.0045
Untrained	1913	35	18.3		
Total	2757	39			
Overall: 2001 and 2002 combined					
Trained	1885	6	3.18	0.1814	<.001
Untrained	3818	67	17.6		
Total	5703	73			
Overall decrease in ACL injury for year 2000	(16.8 – 1.9)/16.8 × 100 = 88%				
Overall decrease in ACL injury for year 2001	(18.3 – 4.74)/18.3 × 100 = 74%				

[a]Rate based on injuries per 1000 players.

TABLE 4
Incidence Rate and Relative Risk of ACL Tears by Team, 2000 and 2001

	No. Teams	No. ACL Tears	Resultant Rate per Player[a]	Relative Risk	P
Year 1: 2000					
Trained	52	2	3.85	0.114	.0003
Untrained	95	32	33.6		
Total	147	34			
Year 2: 2001					
Trained	45	4	8.89	0.284	.0218
Untrained	112	35	31.25		
Total	157	39			
Overall: 2001 and 2002 combined					
Trained	97	6	6.19	0.1911	<.0001
Untrained	207	67	32.37		
Total	304	73			

[a]Rate based on injuries per 100 teams.

intervention group compared to an age- and skill-matched control group in year 2 (see Table 2). When these results were analyzed using the player as a unit of analysis, the injury incidence for the intervention group was 4.74/1000 players compared to 18.3/1000 players for the control group. The resultant rate ratio was equivalent to 0.26, which was statistically significant at $P = .005$ (95% CI, 0.09-0.73) (see Table 3). Using the team as a unit of analysis, the injury incidence rate for the intervention group was 0.08 compared to 0.31 for the control group. The resultant rate ratio was equivalent to 0.28, which was statistically significant at $P = .02$ (95% CI, 0.09-0.85).

When comparing years 1 and 2 of the study, the number of intervention teams decreased from 52 to 45 because the 18-year-old athletes from 2000 were 19 years old in 2001; thus, they were excluded from the study because of the age inclusion/exclusion criteria. In addition, there were 10 fewer teams compiled in the league during the 2001 season (see Table 4).

DISCUSSION

When discussing the nature of the PEP Program for ACL injury prevention, the training that is implemented into the curriculum is seeking to primarily address the feedforward mechanism—to anticipate external forces or loads to stabilize the joint, thus protecting the inherent structures. Several research studies have indicated proprioception may play a major role in injury reduction.[2,4,9,20] Proprioception is described as the acquisition of stimuli by peripheral receptors in addition to the conversion of mechanical stimuli to a neural signal that is transmitted along afferent pathways of the sensorimotor system.[20] Proprioception does not include central nervous system processing of the incoming afferent signal or control of efferent (outgoing) motor signals. However, this "proprioceptive" information is crucial for optimal motor performance. It is delivered to every motor control center and is used to garner information regarding joint position and kinesthesia (joint motion) to elicit active and reflexive movement. Neuromuscular control is defined as the unconscious efferent response to an afferent signal regarding dynamic joint stability. The afferent proprioceptive signals that elicit motor control can be distinguished by their roles: feedback or feed-forward feedback mechanisms are a result of afferent input (force to the joint) and are reflexive in nature. The time to elicit such a reaction is longer; thus, it is thought to be more heavily involved with maintaining posture and slow movement. Feed-forward mechanisms are a result of preactivated preparatory activation of muscle.[9]

Several intrinsic and extrinsic risk factors have been examined to determine the cause of ACL tears. They include anatomical, hormonal, environmental, and biomechanical risk factors.[10]

With regard to anatomy, the variation in morphology between males and females has been well examined, including variances in pelvic size and shape, intercondylar notch width, size of the ACL, ligamentous laxity, and Q angle. In addition, tibial torsion and excessive foot pronation have been examined as potential reasons to the rise of ACL injury.[18] However, no one anatomical risk factor has been directly and independently correlated to an increase in noncontact ACL injury.[10] Perhaps participation in a neuromuscular training program, such as the PEP Program, may impart changes in the strength of the athlete and the biomechanical performance of landing techniques that may decrease the risk of ACL injury.

There has been increasing speculation that the hormonal changes that occur throughout the month may increase a female athlete's susceptibility to ligamentous injury. The menstrual cycle can be subdivided into 3 distinct cycles, which are based on a mean cycle of 28 days. The follicular phase (days 1-9) represents low levels of both progesterone and estrogen. The ovulatory phase (days 10-14) is preceded by a spike of estrogen. The luteal phase (days 15-28) represents a rise in progesterone and a rise in relaxin in the second half of this cycle. Throughout the menstrual cycle, fluctuations in progesterone, estrogen, and relaxin hormones have been studied to determine their effect on the integrity of the ACL. Estrogen, progesterone, and relaxin receptor sites have been found to be present within the ACL.[8,22,33] The increase of estrogen and relaxin hormones has been shown to coincide with a subsequent 40% decrease in the rate of collagen synthesis.[11,32] Slauterbeck et al[35] demonstrated a decrease in tensile properties and a subsequent decrease in the ACL failure load of the estrogen treatment group (rabbits) compared to the control. Wojtys et al[37] noted a statistically significant increase in ACL injury while athletes were in the ovulatory phase (days 10-14) of the menstrual cycle. Myklebust et al,[29] in contrast to the findings of Wojtys et al, found that the ACL injury rate decreased between days 8 and 14. There is some speculation when comparing the collection methods for the hormonal assays and the researcher's method of obtaining them (saliva, urine, or blood). Furthermore, obtaining an account of menstrual status from an athlete in a retrospective fashion may lack accuracy. Therefore, there is no conclusive evidence linking an increase in ACL injury to a predictable time within the menstrual cycle. Further studies investigating the phase of the menstrual cycle, using larger sample sizes, and collecting independent hormonal assays at various times throughout the menstrual cycle are encouraged.

Environmental conditions including weather, playing surface, footwear, and prophylactic and functional knee bracing have been examined. No conclusive studies demonstrate the effectiveness of functional knee braces in preventing noncontact ACL injuries. In 1974, Torg et al[36] developed a quantitative measurement titled the "release coefficient" to describe the force-to-weight ratio of shoe-surface interaction. This work was enforced by Heidt et al,[13] who found that 73% of the 15 different types of athletic shoes tested demonstrated an "unsafe" or "probably unsafe" rating. When considering shoe design, it is important to remember that although an increased friction coefficient may enhance performance, it may also inadvertently increase ligamentous injury. Ekstrand and Nigg[6] noted that there is an optimal range to be incorporated in shoe design—one that will minimize rotational friction to avoid injury yet optimize transitional friction to allow peak performance when performing activities such as cutting and decelerating. Playing surface and shoes must be considered when determining whether these factors can independently increase the rate of noncontact ACL injuries in women.[10] When developing the protocol for the PEP Program, the research team attempted to address the notion of increased friction with deceleration techniques by instituting a 3-step stop-deceleration pattern, as first introduced by Henning and Griffis.[15] By distributing the deceleration force over a series of 3 steps, as opposed to 1 step, the athlete can diminish the ground reaction force and the rotational forces that are generated superiorly and, perhaps, provide a protective benefit to the ACL.

In consideration of the risk factors discussed above, a group of physicians, biomechanists, physical therapists, and athletic trainers met in Hunt Valley, Maryland, in June 1999 to address this ambiguity. The goal of this conference was geared toward developing a strategy to prevent ACL injuries.[10] The group did a thorough review of the existing literature and conferred on several things. In regard to environmental, anatomical, and hormonal risk factors, there is no conclusive evidence that would indicate any 1 single risk factor directly correlating with an increase in severe ACL injuries in the female athlete population. Therefore, the emphasis has turned to biomechanical risk factors and the use of neuromuscular and proprioceptive intervention programs to address potential biomechanical deficits.

Prevention programs focusing on skiing, basketball, and soccer have been performed in the past with results ranging in an overall reduction of severe ACL injuries from 60% to 89%.[3,7,14-17,23,29,31]

Henning and Griffis implemented a prevention study in 2 Division I basketball programs over a course of 8 years geared at changing player technique—stressing knee flexion on landing, using accelerated rounded turns, and decelerating with a multistep stop. They noted an 89% reduction in the rate of occurrence of ACL injuries in their intervention group.[15]

Caraffa et al[3] implemented a proprioceptive balance training program using 600 semiprofessional and amateur soccer players in Italy. The study consisted of a 20-minute training program divided into 5 phases of increasing difficulty. The prospective study was completed over the duration of 3 complete soccer seasons. They found an incidence rate of 1.15 ACL injuries per team per year in the control group compared to a 0.15 incidence rate in the trained athletes. These ratios demonstrated an overall 87% decrease in ACL injuries compared to the control group.

Hewett et al[16] did a prospective analysis of 1263 male and female athletes of various sports using a neuromuscular training program. They used a 6-week intervention program consisting of stretching, plyometrics, and weight training with an emphasis on proper alignment and technique. The authors noted that the incidence of serious knee injury was 2.4 to 3.6 times higher in the untrained group compared to the trained group. When examining the rate of noncontact ACL injuries, 5 untrained female athletes sustained ACL injuries (relative injury incidence, 0.26), no trained females sustained an ACL injury (0), and 1 male athlete sustained an ACL injury (0.05).

Ettlinger et al[7] implemented the "guided discovery" technique in Vermont that focused on avoiding high-risk behavior and positioning (ie, "phantom foot"), recognizing potentially dangerous skiing situations, and responding quickly to unfavorable conditions. During the 1993-1994 ski season, 4700 ski instructors and patrollers completed the comprehensive training program at 20 ski areas throughout the United States. As a result, the rate of serious knee injuries decreased by 62% among the trained individuals compared to those who did not participate in the training program.

Heidt et al[14] studied 300 female soccer players between the ages of 14 and 18 years over a 1-year period. Forty-two athletes participated in the Frappier Acceleration Training Program, a 7-week preseason training program consisting of strength training, flexibility, sports-specific cardiovascular exercise, plyometrics, and sports-cord drills. They found that the trained group incurred a lower percentage of ACL injuries (2.4%) compared to the age-matched control group (3.1%).

Myklebust et al[29] instituted a proprioceptive training program in elite female team handball players. This 5-phase training program consisted of floor exercises, wobble board activities, and a balance mat performed 2 to 3 times a week over the course of 5 to 7 weeks in the preseason and once a week during the season. Fifty-eight teams (855 players) participated in the first season (1999-2000), and 52 teams (850 players) participated in the second season (2000-2001). Sixty teams (942 players) in the 1998-1999 season served as the control. There were 29 ACL injuries in the control season, 23 ACL injuries in the first intervention season, and 17 injuries in the second intervention season.

The similarities between the Santa Monica PEP Program and the intervention studies described above are numerous. An emphasis on activities such as having a proper landing technique; engaging knee and hip flexion on landing and lateral maneuvers; avoiding excessive genu valgum at the knee on landing and squatting; increasing hamstring, gluteus medius, and hip abductor strength; and addressing proper deceleration techniques seems to be inherent in each of the aforementioned ACL prevention protocols. Further EMG and biomechanical analysis is warranted to understand and identify the activities that offer a protective effect to the ACL. In addition, the rate of ACL injury reduction in the protocols discussed above ranged from 60% to 89%; the PEP Program rate of injury reduction was similar, ranging from 74% to 88%.[3,7,14-16,23,29]

Study Limitations

We recognize the inherent limitations of the present study. First and foremost, the study was a nonrandomized prospective study design. Voluntary enrollment of the intervention group may have led to a "Hawthorne effect," which is defined as an experimental effect in the direction expected but not for the reason expected—that is, a significant positive effect that turns out to have no causal basis in the theoretical motivation for the intervention but is apparently owing to the effect on the participants of knowing themselves to be studied in connection with the outcomes measured.[30] A selection bias or motivational bias may have affected the overall decrease in ACL injury rates in the intervention group, as the teams that opted to participate may have had a greater interest in injury prevention. However, the control subjects had no knowledge that they were excluded from the study and were grossly unaware of the existence of the PEP Program, as this alternative warm-up was offered to the coach of the team without the individual athlete's knowledge. Subjects were not randomly striated into the intervention or control groups. However, because of the large sample size and the fact that we controlled for age and skill (intervention vs control), the selection or motivation bias due to nonrandomization may be minimal.

CONCLUSION AND FUTURE DIRECTIONS

The results of this study indicated that a neuromuscular training program, such as the PEP Program, may significantly reduce the incidence of severe ACL injuries in the female athlete. The results of this study were akin to those prevention programs developed for basketball players, amateur and professional male soccer players, skiers, and volleyball athletes.[3,7,14-16,23,29] It is our position that a prophylactic training program that focuses on developing neuromuscular control of the lower extremity through strengthening exercises, plyometrics, and sports-specific agilities may address the proprioceptive and biomechanical deficits that are demonstrated in the high-risk female athletic population.

It has been shown that the incidence of ACL injuries can be reduced through comprehensive neuromuscular training methods. Now, the impetus to determine the precise biomechanical changes that are being instituted from these prophylactic programs that enable these athletes to avoid severe ACL injury is crucial. It is known that a large number of noncontact ACL injuries occur during the deceleration phase of a cutting maneuver, when a rotation torque in concert with a varus-valgus moment is applied to a knee that is flexed 10° to 30°.[5,19,28] Markolf et al[27] noted that both a varus moment and internal rotation moment at the knee will place the ACL at a greater risk for injury as opposed to valgus and external rotation moments. Sigward et al[34] proposed that female athletes demonstrating a combination of internal rotation and varus moments in the first 20% of the cut cycle may be at a greater risk for ACL rupture. This "pathokinetic chain" is described as a combination of an increased hip adduction moment, a decrease in hip abduction control, and an increase in hip adduction angles, thus placing the lower extremity in a valgus position. Theoretically, when this position is combined with an increase in an internal rotation moment and motion at the knee joint, the ACL incurs an increase in tension (newton). When the ground reaction force is considered, which falls medial to the knee joint during a cutting maneuver, this position may tax an already tensioned ACL and lead to failure. This research group is seeking to further study the biomechanical implications of instituting the PEP Program via EMG and force plate analysis, to identify the mechanism of ACL injury, and, finally, to determine a precise neuromuscular intervention program that will specifically counteract the unopposed forces around the trunk and lower extremity to further decrease the incidence of severe ligamentous injury.

SUMMARY

The relationship of gender, age, and training on the incidence of ACL injury is pivotal in developing a comprehensive neuromuscular and proprioceptive training program to decrease ACL injuries occurring in female athletes. Based on the 2-year results, the incidence of ACL injury has remained consistently lower in the intervention group versus the control group. A prophylactic neuromuscular and proprioceptive training program may have a direct benefit in decreasing the number of ACL injuries incurred by female athletes. This research foundation endorses further epidemiological and biomechanical studies to determine the exact mechanism of ACL injury and the most effective intervention to decrease ACL injuries in this high-risk population.

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