Lack of Effect of a Knee Ligament Injury Prevention Program on the Incidence of Noncontact Anterior Cruciate Ligament Injury

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Background: Studies have suggested that exercise programs can reduce the incidence of noncontact injuries of the anterior cruciate ligament in female athletes. We conducted a two-year prospective study to assess the effects of a knee ligament injury prevention exercise program on the incidence of noncontact anterior cruciate ligament injuries in high-school female athletes.

Methods: A prospective cohort design was used to study high-school female athletes (playing soccer, basketball, and volleyball) from fifteen schools (112 teams) for two consecutive seasons. The schools were divided into treatment and control groups. The treatment group participated in a plyometric-based exercise program twice a week throughout the season. Practice and game exposures and compliance with the exercise program were recorded on a weekly basis. Suspected noncontact anterior cruciate ligament injuries were confirmed on the basis of the history as well as at the time of surgery and/or with magnetic resonance imaging.

Results: A total of 1439 athletes (862 in the control group and 577 in the treatment group) were monitored. There were six confirmed noncontact anterior cruciate ligament injuries: three in the treatment group, and three in the control group. The incidence of noncontact anterior cruciate ligament injuries per 1000 exposures was 0.167 in the treatment group and 0.078 in the control group, yielding an odds ratio of 2.05, which was not significant ($p > 0.05$).

Conclusions: Our results suggest that a twenty-minute plyometric-based exercise program that focuses on the mechanics of landing from a jump and deceleration when running performed twice a week throughout the season will not reduce the rate of noncontact anterior cruciate ligament injuries in high-school female athletes.

Level of Evidence: Therapeutic Level II. See Instructions to Authors for a complete description of levels of evidence.

Over the last two decades, many studies have demonstrated that female athletes sustain injuries to the anterior cruciate ligament four to six times more frequently than do their male counterparts[1-11]. Although the majority of anterior cruciate ligament injuries occur in males, it has been estimated that approximately 38,000 female athletes sustain this injury annually[12]. The majority of anterior cruciate ligament injuries reported in athletes are noncontact injuries, sustained during sudden deceleration when running, changing direction, or landing from a jump[13,14].

In order to determine the etiology of this high injury rate in female athletes, numerous intrinsic and extrinsic factors have been studied[2]. Recent studies of female athletes have demonstrated that females land from a jump and change direction in a more erect posture than do males, with the knees and hips at angles close to full extension. This posture in association with increased contraction of the quadriceps may be more antagonistic to the anterior cruciate ligament and increase the risk of anterior cruciate ligament injury[15-20]. The role of the hamstrings as anterior cruciate ligament agonists is still being studied, although a relationship is strongly supported in the literature[15,16,19,21,22]. Related studies have shown that females, particularly postpubescent females, often demonstrate neuromuscular strategies that result in a greater knee valgus angle in conjunction with a reduced internal knee varus moment when performing a landing or cutting task[23-30].

Training programs have been developed to alter landing mechanics and improve lower extremity strength, with

TABLE I Phases and Exercises of the Knee Ligament Injury Prevention (KLIP) Program*

Phase 1 (Wk 1 and 2)	Phase 2 (Wk 3 and 4)	Phase 3 (Wk 5 and 6)	Phase 4 (Wk 7 to End of Season)
Straight jumps	Straight jumps	Tuck jumps	Straight jumps
Tuck jumps	Tuck jumps	Single-leg lateral leaps	Single-leg forward hops × 3
Standing broad jump	180's	Single-leg forward hops	Combination jumps
Bound in place	Double-leg jumps	Combination jumps	180's
	Single-leg lateral leaps	180's	Standing broad jumps
	45° lateral leaps	45° lateral leaps	Single-leg 45° lateral hops

*Additional agility drills done after the jump program include stop and go, "W" drill, figure-of-eights, and left/right cuts.

the goal of reducing knee injuries in athletes[31-41]. A number of studies of these programs were critically evaluated by researchers affiliated with the Centers for Disease Control and Prevention[42]. This review identified and evaluated the quality of the methodology of six prospective studies that addressed knee injury prevention through targeted training programs [36-38,40,43,44]. The article noted major flaws in the designs of all of the studies but suggested that further evaluation of these training programs is warranted.

The purpose of this prospective study was to evaluate the effectiveness of a specialized exercise intervention program in reducing the incidence of noncontact injuries of the anterior cruciate ligament in a cohort of high-school female athletes. Specifically, the exercise program—called the *Knee Ligament Injury Prevention (KLIP) program*—focuses on improving jump-landing and running-deceleration mechanics with the goal of reducing the risk of noncontact anterior cruciate ligament injuries. The KLIP program was shown to be effective for improving landing mechanics by decreasing peak vertical impact force and the rate of force development in a cohort of college females[45].

Materials and Methods

Fifteen high schools (112 girls' teams) located in the Treasure Valley in southwestern Idaho participated in the study over the course of two competitive seasons. Three sports (soccer, volleyball, and basketball) at the varsity, junior varsity, and sophomore levels were monitored. Schools were selected on the basis of their willingness to participate and on the availability of National Athletic Trainers' Association Board of Certification-certified athletic trainers to assist with the study.

Prior to its initiation, this study was approved by the institutional review board at Boise State University, and permission was obtained from the appropriate school administrators at all of the schools involved in the study. Schools were placed into either the treatment group (KLIP training) or the control group (no KLIP training) on the basis of their willingness to incorporate the KLIP training into their daily practice routines.

In order to avoid a possible Hawthorne effect[46] in the control group teams, special effort was made by our research staff to avoid direct contact with any of the athletes on those teams. To our knowledge, the athletes in the control schools were unaware that they were being monitored for serious knee injuries beyond what would normally be done by their athletic department personnel.

The KLIP program was designed by a development team that included an exercise physiologist, athletic trainers, physical therapists, and physicians. Designed to be incorporated at either the beginning or the end of practice, the program can be completed in approximately twenty minutes. Hewett et al. studied the effects of an intervention program implemented at the high-school level that involved jump-training and strength and flexibility exercises requiring sixty to ninety minutes per day, three days per week[38]. Because of limited practice time for many youth-sport and school-based programs, the KLIP program was designed to require less time than that program. The focus of the KLIP program is on the development of sound body mechanics when decelerating during running with directional changes and when landing on one or two feet. Many of the drills incorporated into the KLIP program involve jumping and landing with two-footed drills progressing to one-footed drills, in both forward and backward directions. The jumping/hopping portion of the KLIP program utilizes a form of plyometric training in that many of the drills involve jumping and landing followed immediately by another jump. In addition, agility drills such as the "W" drill in which the athlete runs forward, stops, runs backward, and repeats, in the pattern of the letter "W" are incorporated along with coaching points focused on teaching proper body position (alignment of the hip, knee, and ankle) when weight-bearing. The program is sequential and progressive in that it incorporates four phases with each subsequent phase based on skills developed in previous phases. Once the athlete can demonstrate proficiency in a given set of skills, she progresses to the next level of skill difficulty. The phases and the specific skills to be mastered in each are listed in Table I.

All of the teams that participated in the treatment group received personal instruction in the implementation of the KLIP program, instructional videotape, and printed handouts. All participating team coaches received data-reporting forms and were asked to track all players on their respective rosters relative to their participation in weekly practices and games and, in the case of the teams at the treatment schools, the number of KLIP training sessions per week. A player-exposure was defined as one player participating in either one

practice or one game on a given day. Data-reporting forms were collected weekly.

All participating coaches and/or their respective athletic trainers were asked to report any suspected noncontact anterior cruciate ligament injuries to the principal investigator (R.P.P.) by telephone or e-mail. For the purposes of this study, a noncontact anterior cruciate ligament injury was defined as an anterior cruciate ligament injury resulting from a mechanism of running and cutting (abrupt deceleration associated with a directional change) or landing from a jump. Contact was defined as direct contact of the player's knee region with an opponent or another form of collision, such as with an inanimate object. After the injury was reported, its status was verified with magnetic resonance imaging or at surgery. Reinjuries and contact injuries were recorded but excluded from the statistical analysis. A total of 1439 athletes were monitored over the course of two competitive seasons (two consecutive years). There were 862 athletes (on a total of sixty-nine teams) in the control group and 577 athletes (on forty-three teams) in the treatment group. Table II provides a breakdown of the numbers of athletes by sport in both the treatment and the control group.

Statistical Methods

The probability of a noncontact anterior cruciate ligament injury occurring on a team was modeled with use of logistic regression. This method is appropriate for binary outcomes (injured or not injured)[47]. While the team's inclusion in the treatment or control group was the primary independent variable under study, the number of players and the total number of exposures on the team were also included in the model as controlling variables. Modeling incidence at the team level was required because patient confidentiality restrictions did not allow us to identify which athlete was injured. However, analysis at this level allowed us to sidestep issues of statistical dependency among players on the same team. Because of the few noncontact anterior cruciate ligament injuries, exact methods were used to fit the models and estimate odds ratios with use of LogXact 5.0 software (Cytel, Cambridge, Massachusetts, 2002). The level of significance was set at $p \leq 0.05$.

Results

Ten knee injuries were reported over the course of the two-year study period; however, only six met the criteria for a noncontact anterior cruciate ligament injury and were included in the data analysis. Three noncontact anterior cruciate ligament injuries occurred in the treatment group and three, in the control group. Of the injuries that were not included in the analysis, three involved the anterior cruciate ligament but were determined to be the result of contact and an additional anterior cruciate ligament injury was determined to be a reinjury of a previously reconstructed anterior cruciate ligament. Five of the six noncontact anterior cruciate ligament injuries occurred while the athlete was playing basketball, and one occurred while the athlete was playing soccer. A total of 56,616 player-exposures was recorded for the two-year duration of this study. Injury incidence was expressed as the number of noncontact anterior cruciate ligament injuries per 1000 player-exposures. There were 38,662 player-exposures and three noncontact anterior cruciate ligament injuries in the control group, yielding an incidence of 0.078 per 1000 exposures. There were 17,954 player-exposures and three noncontact anterior cruciate ligament injuries in the treatment group, yielding an incidence of 0.167 per 1000 exposures.

As the injury distribution was not even across sports, we also examined the injury incidence according to player-exposure in the sports in which there were noncontact anterior cruciate ligament injuries (Table III). In the control group, basketball produced two noncontact anterior cruciate ligament injuries as a result of 18,076 player-exposures, for an incidence of 0.111 per 1000 player-exposures, and soccer produced one noncontact anterior cruciate ligament injury as a result of 9357 player-exposures, for an incidence of 0.107 per 1000 player-exposures. In the treatment group, basketball produced three noncontact anterior cruciate ligament injuries as a result of 6302 player-exposures, for an incidence of 0.476 per 1000 player-exposures.

Compliance with the KLIP training was recorded and the data were collected on a weekly basis from all participating teams in the treatment group. The average number of KLIP training sessions per player was eighteen, twenty-three, and twenty-two on the basketball, soccer, and volleyball teams, respectively. A table in the Appendix provides the total season average KLIP training sessions per athlete and per team.

Nearly 60% more teams/levels (varsity, junior varsity, and sophomore) participated as controls than as treatment groups. The control schools had about 50% more athletes than the treatment schools and more than twice as many total expo-

TABLE II Number of Schools and Athletes in Each Study Group

	Control Group		KLIP Group		Total	
Sport	No. of Teams/Levels*	No. of Players	No. of Teams/Levels*	No. of Players	No. of Teams/Levels*	No. of Players
Basketball	28	319	17	191	45	510
Soccer	14	244	11	189	25	433
Volleyball	27	299	15	197	42	496
Total	69	862	43	577	112	1439

*Levels = junior varsity, varsity, or sophomore.

TABLE III Incidence Rates per 1000 Exposures by Study Group and Sport

Group/Sport	No. of Noncontact Anterior Cruciate Ligament Injuries	No. of Total Exposures*	Incidence *(per 1000 exposures)*
Control	3	38,662	0.078
Basketball	2	18,076	0.111
Soccer	1	9357	0.107
Volleyball	0	11,229	—
KLIP	3	17,954	0.167
Basketball	3	6302	0.476
Soccer	0	5913	—
Volleyball	0	5739	—
Total	6	56,616	

*The total number of practices and games in which the athletes participated.

sures. In spite of this, the average weekly numbers of practices (40.1 compared with 44.3) and game exposures (21.3 compared with 20.9) per individual were very similar between the control and treatment groups (see Appendix).

The logistic regression model allowed us to compare the odds of a noncontact anterior cruciate ligament injury occurring between the treatment and control groups while controlling for both exposure and number of players. The odds of injury were equivalent for the two groups (odds ratio = 2.05; 95% confidence interval = 0.21 to 21.7). The number of players on the team and the total team exposure also were not significant predictors of noncontact anterior cruciate ligament injuries. A table in the Appendix shows the model results.

Discussion

Despite the high number of female athletes (1439) and exposures (56,616) in this prospective study, we failed to demonstrate a significant difference in the rates of noncontact anterior cruciate ligament injuries between a group treated with a specific preventative exercise program and a control group. The strengths of the study included a prospective protocol, relatively large numbers of participants in both the treatment and the control groups, careful monitoring of program compliance and weekly exposures, and confirmation of all noncontact anterior cruciate ligament injuries.

The study also had several limitations. The overall rate of anterior cruciate ligament injury was lower than had been expected on the basis of other epidemiologic studies in the literature[9,38,48]. Future prospective studies may need to address a lower rate of noncontact anterior cruciate ligament injury and to survey larger numbers of study subjects. Another limitation of our study was the nonrandomized design. We had originally intended to randomize the treatment and control groups, but many of the school administrators and coaches were not willing to participate in a randomized study.

In contrast to our study results, Hewett et al. reported a significant difference in the incidence of noncontact knee injury ($p = 0.01$) as well as noncontact anterior cruciate ligament injury ($p = 0.05$) between trained and untrained groups in their study of high-school female athletes[38]. However, their treatment and control groups were quite different with respect to the distribution of the participants in the three sports. In their control (untrained) groups, 17% of the athletes were volleyball players, 41% were basketball players, and 42% were soccer players. In contrast, in their treatment group, 51% of the athletes played volleyball; 23%, basketball; and 27%, soccer. These relatively large disparities in the distributions of the athletes among the sports may have influenced their results. The distribution of the athletes among the three sports in our study was quite similar between the control and treatment groups.

Another difference between the study by Hewett et al.[38] and our study was the type of training program. Although the training program in the study by Hewett et al. incorporated plyometric-type exercises, commonly called "jump training," it also included both flexibility and strength-training exercises. Furthermore, their training program was completed prior to the onset of the sports season and required approximately sixty to ninety minutes per day, three times per week. In contrast, our program required approximately twenty minutes per session during the playing season, focused primarily on jump-landing and run-deceleration mechanics, and did not incorporate specific flexibility or strength-training components. Strength-training may be a critical factor in injury prevention programs, and this variable should be considered in future studies.

Several other exercise intervention studies have demonstrated significant reductions in noncontact anterior cruciate ligament injuries in their trained groups. In the majority of those studies, the investigators examined the effects of exercise programs that focused on balance and proprioceptive training with use of balance boards alone[36], balance boards and mats in combination with ball-handling tasks[39,41], or some form of plyometric or jump training[37,38]. The results of those studies are equivocal regarding prevention of anterior cruciate ligament injuries. Caraffa et al. reported a dramatic decrease in the incidence of anterior cruciate ligament injuries, over three seasons, in semiprofessional soccer players who completed a

program of progressive balance-board training for twenty minutes per day at least three times per week[36]. Heidt et al. examined the effect of a seven-week progressive plyometrics program on the rate of anterior cruciate ligament injuries in forty-two fourteen to eighteen-year-old female soccer players[37]. While the overall incidence of injuries to the lower extremities was reduced in their training group, no effect of the training program was found when anterior cruciate ligament injuries were examined separately. Myklebust et al. studied the effect of a program of balance exercises in a large cohort of female team handball players over the course of three consecutive seasons[41]. They concluded that, with all skill levels combined, there was no difference in the incidence of anterior cruciate ligament injury between their trained and untrained groups. However, they did find a significant difference in the risk of anterior cruciate ligament injury in the elite division ($p = 0.01$). Their conclusion was that, at the elite level, compliance with the training program may have been sufficient to convey a protective effect. Soderman et al. examined the effects of a program of balance-board training on the incidence of injuries to the lower extremities in female soccer players[39]. It is interesting to note that when they examined the rates of severe knee injuries alone, they found a higher rate of anterior cruciate ligament injuries in their intervention group than in their control group.

In a recent review from the Centers for Disease Control and Prevention, Thacker et al. demonstrated methodological problems with studies of exercise intervention to reduce the risk of knee injury[42]. They recommended that future studies be randomized controlled trials with selection of subjects as well as data analysis being blinded to reduce bias[42]. As we discovered, implementing these types of exercise studies can be challenging because many coaches are unwilling to modify their practice protocols.

On the basis of our results and those of related studies, it appears that more research is needed to verify the ability of exercise programs to reduce the incidence of noncontact anterior cruciate ligament injuries in athletes. Also, more laboratory work is needed to clearly define landing mechanics that place athletes at risk for these injuries as well as the effects that training programs may have on altering landing mechanics. Until training programs unequivocally demonstrate a clear benefit to the athletes in terms of reducing noncontact anterior cruciate ligament injuries, coaches may resist implementation of these training regimens.

Appendix

eA Tables showing the numbers of training sessions, the exposures by group and sport, and the results of the regression analysis are available with the electronic versions of this article, on our web site at jbjs.org (go to the article citation and click on "Supplementary Material") and on our quarterly CD-ROM (call our subscription department, at 781-449-9780, to order the CD-ROM). ■

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