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Effects of a Knee Ligament Injury Prevention Exercise Program on Impact Forces in Women

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Abstract. Irmischer, B.S., C. Harris, R.P. Pfeiffer, M.A. DeBeliso, K.J. Adams, and K.G. Shea. Effects of a knee ligament injury prevention (KLIP) exercise program on impact forces in women. *J. Strength Cond. Res. 18(4):000–000. 2004.*—Previous research suggests high impact forces generated during landings contribute to noncontact anterior cruciate ligament (ACL) injuries. In women, neuromuscular differences appear to modify the ability to dissipate landing forces when compared to men. This study examined peak vertical impact forces (F_p) and rate of force development (RFD) following a 9-week, low-intensity (simple jump-landing-jump tasks) and volume (number of foot contacts per workout) plyometric-based knee ligament injury prevention (KLIP) program. Female subjects were randomly assigned into control ($n = 14$) and treatment ($n = 14$) groups. Treatment subjects attended KLIP sessions twice a week for 9 weeks, and control subjects received no intervention. Ground reaction forces (F_p and RFD) generated during a step-land protocol were assessed at study onset and termination. Significant reductions in F_p ($p = 0.0004$) and RFD ($p = 0.0205$) were observed in the treatment group. Our results indicate that 9 weeks of KLIP training altered landing strategies in women to lower F_p and RFD. These changes are considered conducive to a reduced risk of knee injury while landing.

Key Words. rate of force development, plyometrics, landing mechanics

Introduction

Women participating in sports that involve a substantial amount of jumping and pivot turns, such as soccer, volleyball, and basketball, are more susceptible to knee injuries than their male counterparts (1, 4, 18, 19, 28, 29, 30, 31). There are an estimated 38,000 anterior cruciate ligament (ACL) injuries in women every year; 2,200 of these injuries occur in collegiate athletics (1, 20, 32). The severity of the situation is compounded by the fact that ACL injuries require surgery more often in women than in men (1, 2, 31). Noncontact mechanisms have been identified as the leading causes of ACL injuries in female athletes (1, 2, 13). These mechanisms include less than optimal landing strategies combined with elevated impact forces and rapid decelerations that occur when landing from a jump or performing a cut-and-turn maneuver (4, 13, 16). Consequently, the highest numbers of ACL injuries in women are found in sports that include rapid deceleration, pivot turns, and jumping, such as soccer, volleyball, and basketball (1, 2, 13).

Biomechanical risk factors for ACL injury include the maintenance of dynamic stability around the knee through neuromuscular control and the magnitude and rate of impact forces generated during landing (12). The musculoskeletal elements of the lower extremities must distribute forces incurred when landing while maintaining stability. When the impact forces become too high, these elements cannot adequately dissipate the stresses, and the potential for injury arises. When landing from a jump, women generate higher peak impact forces than men do over shorter periods of time (16). This predisposes women to a greater risk of ACL injury (16). Neuromuscular differences in women appear to be the single factor that contributes most to the increased incidence of ACL injury (16, 21). Training programs for women that focus on neuromuscular control of the lower extremities may be effective in modifying landing mechanics and, subsequently, in helping to prevent noncontact ACL injuries.

Plyometric and proprioceptive training studies have shown promising results in manipulating landing technique (6, 14–16). In a study of female high school athletes, peak landing forces were reduced following 6 weeks of stretching, resistance, and plyometric training (16). A follow-up study in female athletes with similar training methodology demonstrated a significant reduction in the total number of serious knee injuries (15). However, the training program utilized in both studies (15, 16) may be unrealistic for many young women because of large time demands and a plyometric program designed with high intensities and volumes.

Many women join organized sports that involve jumping without possessing adequate levels of muscular strength and power. Without the proper base level of fitness, the ability of these individuals to safely participate in these sports is questionable. Also in question is the ability to tolerate a high-intensity, high-volume, plyometric training program such as those employed by earlier studies (15, 16). The effects on impact forces in women of an easily implemented plyometric program with low intensity and volume have not been addressed (15, 16). Thus, the purpose of this study was to examine the effect of a lower extremity plyometric training program of low intensity and volume on the peak vertical impact forces (F_p) and rate of force development (RFD) in women landing from a jump. By learning more about the status of landing strategies in women and seeking effective change in these strategies via specific exercise programs, we may be able to reduce noncontact ACL injuries.

Methods

Experimental Approach to the Problem

This study employed a prospective, longitudinal design to examine the effect of an easily implemented, low-intensity and volume, plyometric training program on impact forces and rate of force development experienced by active women when landing from a jump. Random assignment created a control group and a treatment group to examine this question over 9 weeks of training that targeted neurological adaptation. The knee ligament injury prevention (KLIP) training program was designed based on previous experiences of sports medicine clinicians and injury prevention research. Low intensity was achieved by incorporating only simple, plyometric-based jump-landing-jump tasks suitable for the general active population. Volume, as measured by foot contacts, was kept low in order to assess the effects of a program that would be feasible to implement into a busy training and life schedule. Training was designed in a manner that allowed us to control and carefully monitor the exercise technique and prescription. Training emphasized landing mechanics and neuromuscular control at landing; increasing vertical jump was not the goal. Results can only be generalized to active, college-aged women. Highly competitive female athletes may respond differently.

Subjects

Physically active (i.e., at least 30 minutes of aerobic activity 3 times a week for the past 3 months) women were recruited from the general university student population ($N = 28$, mean age $= 24.0 \pm 4.0$ years). Subjects were randomly assigned into control ($n = 14$) and treatment ($n = 14$) groups. Participants were required to have a 5-year history free of knee problems. All subjects completed health history questionnaires to assess orthopedic soundness. Any problems were cited as grounds for elimination. Prior to testing, subjects signed an informed consent document approved by the Boise State University institutional review board for the use of human subjects in research.

Force Testing

Force analysis tests were conducted on a step land protocol to determine F_p and RFD. Data were collected using a Kistler multicomponent measuring plate (Kistler Instruments Corp., Amherst, NY) at 600 Hz for 1.5 seconds. Testing was conducted at study onset and termination. A step-land protocol was employed with a 0.69-m drop distance. A coin was flipped to determine the step-off leg. After a 3-second countdown, subjects stepped away from a platform and landed on the force plate with both feet. A brief rest was allowed while recording systems were reset for the next trial. Each subject was given 3 practice trials followed by 6 data collection trials. At no time during testing were instructions provided concerning landing strategies.

Force data were normalized to body weight to allow for comparison across subjects. F_p was determined as follows:

$$F_p = \frac{F_{max-1} + F_{max} + F_{max+1}}{3}$$

where F_{max} was the highest force value recorded, F_{max-1} was the sample prior to F_{max}, and F_{max+1} was the sample after F_{max}. RFD was determined by

$$RFD = \frac{F_p}{T_p} \tag{2}$$

where T_p was the time from force plate contact to F_{max}.

Vertical Jump Testing

Vertical jump height was assessed at study onset and termination using a Vertec device (Questek Corp., Northridge, CA). The Vertec device allows jump height to be measured to the nearest 0.0127 m. Vertical jump height was defined as the difference between the maximum jump height achieved by both hands during a jump minus the 2-handed standing reach height. An arm swing and counter-movement were allowed; however, a step-up was not permitted. Subjects were allowed 3 trials, and maximum height was recorded.

Jump Training Program

Research into mechanisms of knee injury has generated a great deal of interest in designing preventive programs. The lower extremity plyometric program used is known as the knee ligament injury prevention (KLIP) training program. KLIP is based on injury prevention research and first-hand experiences of sports medicine professionals in injury prevention and rehabilitation. Objectives of KLIP are to reduce the peak force and rate of force development during landing. Jumping technique is often taught in athletic practice; however, the landing aspect is neglected. Improved control can be observed through modification of landing techniques and enhanced total body control and joint stabilization (3, 13, 20). In past studies, technical instruction regarding proper landing technique (21, 30) and video analysis (26) resulted in significant reductions in impact forces. Therefore, KLIP instruction included information on proper joint positioning of the hips, knees, and ankles. In addition, subjects were directed to listen to the sound of their impact, because past studies have demonstrated significant reductions in impact force with this technique (21, 30).

Treatment subjects attended training sessions twice a week for 9 weeks, and control subjects received no intervention. Both groups were asked to maintain their normal fitness regime and refrain from initiating novel fitness activities for the duration of the study. Supervised training sessions lasted approximately 20 minutes. At least 48 hours of rest were required between training days. Light calisthenics and stretching occurred before and after training sessions. During the first training session, subjects watched a video describing the proper mechanics of landing and correct technique for each of the exercises. At each session, the prescribed exercises were demonstrated and the number of sets and repetitions were explained. Attendance was monitored.

There were 4 phases of the program (Table 1). Each of the first 3 phases lasted 2 weeks and the final phase lasted 3 weeks. Four low-intensity exercises were performed in phases 1 and 2, and 6 low-intensity exercises were performed in phases 3 and 4. High-intensity maneuvers were not included in KLIP. KLIP is a simple, low-intensity, plyometric-based program that incorporates jump-landing-jump tasks suitable for the general active population. Volume, or the number of foot contacts per session, increased from 110 to 218 over the course of training. Volume was kept low for ease of implementation into a busy training and life schedule.

During phases 1 and 2, the following exercises were performed: "wall jumps"—bouncing up and down on the toes with arms overhead; "jump tucks"—jumping from a standing position and bringing the knees to the chest;

TABLE 1. KLIP training program.*

Phase (fc)	Exercise	Sets × repetitions
1 (110 fc)	Wall jumps	3 × 10
	Jump tucks	3 × 10
	Standing broad jump	1 × 10
	Bound in place	2 × 10 (each leg)
2 (160 fc)	Wall jumps	3 × 10
	Jump tucks	3 × 10
	180°s	2 × 5 (each way)
	Double leg hops × 2	2 × 5
3 (210 fc)	Jump tucks	3 × 10
	Single leg lateral hop	3 × 5 (each leg)
	Single leg forward hop	2 × 5 (each leg)
	Double leg hops × 3 w/vertical jump at end	1 × 5
	180°s	3 × 5 (each way)
	Single leg 45° lateral hops	2 × 10 (each leg)
4 (218 fc)	Wall jumps	3 × 10
	Single leg forward hops	3 × 3 (each leg)
	Double leg hops × 3 w/vertical jump at end	2 × 5
	180°s	4 × 5
	Standing broad jump	2 × 10
	Single leg 45° lateral hops	2 × 10 (each leg)

* KLIP = knee ligament injury prevention; fc = number of foot contacts.

TABLE 2. Descriptive information (mean ± *SD*) at study onset.

	Control	KLIP*
Age (yr)	24.3 ± 4.3	24.0 ± 5.0
Weight (kg)	62.0 ± 6.4	65.3 ± 10.5
Height (m)	1.7 ± 0.1	1.7 ± 0.1

* KLIP = knee ligament injury prevention group.

"bounding in place"—jumping off of one leg from the ground and landing on the opposite leg while maintaining a horizontal position; "180s"—performing a vertical jump with a 180° rotation in the air; and "standing broad jump and double leg hops"—performing either 1 or 2 consecutive broad jumps. In phases 3 and 4, several single-leg maneuvers were added. The exercises were simple modifications to the bound-in-place exercise, except the orientation of the jump was either lateral (single leg 45° lateral hop) or forward (single-leg forward hop) for a distance of approximately 0.6 m. Vertical displacement was minimal. On the forward hop, take-off and landing were done from the same leg. On the lateral hop, the take-off and landing leg were different.

Statistical Analyses

Statistical analysis was conducted using StatView (SAS, Inc., Cary, NC). The effect of treatment on each dependent variable was assessed using a 2 × 2 (group by variable) analysis of variance (ANOVA) with repeated measures. Dependent variables included jump height, F_p, and RFD. Alpha levels less than 0.05 were required to demonstrate a significant difference. Significant differences observed for within- and between-group variables were further examined via paired and independent *t*-tests.

RESULTS

Descriptive statistics are provided in Table 2. Thirty-two subjects were originally recruited for the study. However, 2 subjects in the control group were unable to participate in posttesting and 2 subjects in the treatment group did not meet the minimum training compliance of 75%. Subjects in the treatment group averaged 16.7 KLIP sessions, representing 93% compliance.

TABLE 3. Dependent variables (mean ± *SD*) for control and KLIP groups at study onset and termination.†

	Control	KLIP
F_p (bw)		
Pre	5.8 ± 1.7	5.3 ± 1.0
Post	5.5 ± 1.6	3.9 ± 0.6*
RFD (bw/ms)		
Pre	0.13 ± 0.06	0.11 ± 0.03
Post	0.12 ± 0.06	0.08 ± 0.02*
Jump Height (m)		
Pre	0.35 ± 0.05	0.35 ± 0.04
Post	0.38 ± 0.06	0.40 ± 0.05

* $p < 0.05$
† KLIP = knee ligament injury protection; F_p = peak vertical impact forces; bw = bodyweight; RFD = rate of force development; ms = meters per second.

The means ± standard deviations (mean ± *SD*) for each dependent variable are listed in Table 3. There were no significant differences ($p < 0.05$) in any parameter between the control and treatment (KLIP) groups at study onset. The KLIP group experienced a significant reduction in F_p and RFD from the training program ($p = 0.0004$ and $p = 0.0205$, respectively). No change ($p > 0.05$) occurred in F_p or RFD for the control group. At posttest KLIP's F_p and RFD at landing were significantly lower than the control group's ($p = 0.002$ and $p = 0.0045$, respectively). As expected, neither group experienced a significant change in vertical jump. However, a positive trend (control = +8.6%; KLIP = +14.3%) was observed in both groups, possibly reflecting a learning effect from the jump trials.

DISCUSSION

Research suggests a large percentage of ACL injuries in females occur while landing from a jump (4, 8, 10–12), due to a combination of high peak-impact forces and poor lower extremity neuromuscular control. Previous research has utilized plyometric and proprioceptive training programs to improve landing mechanics in an effort to prevent injury (5, 15, 16). The purpose of this study was to determine if a knee ligament injury prevention program (KLIP), consisting of lower extremity plyometric training of low intensity and volume could reduce F_p and RFD during jump landings in women. Our results demonstrate that 9 weeks (18 sessions) of KLIP training is successful in altering landing strategies of women to significantly decrease F_p and RFD. These changes are considered conducive to a reduced risk of knee injury.

In the current study, peak impact forces at landing were reduced by an average of 26.4%. Rate of force development at landing was also reduced by 27.3%. As we teach athletes to jump higher and higher, the importance of proper landing technique becomes more important in order to dissipate increased forces. ACL rupture occurs when the load applied across the knee is too great to be dissipated safely (20), as is often seen in landing when body position is uncontrolled (8–11) and forces several times body weight must be absorbed to prevent injury. It is the role of the bones and soft tissue to safely dissipate these forces and bring momentum to zero (23). When landing forces are too high and combined with rapid loading rates, the neuromuscular system is challenged and joint degeneration and bone or tendon fractures are possible (7, 24, 25).

Impact forces during landing are affected by drop/jump height, degree of knee flexion, and knee rotation (9, 16, 22, 24). For example, the higher velocities generated when landing from increased elevations raise the total impulse that must be dissipated, typically resulting in a higher peak force (22). Landing with the lower extremities in a stiff configuration (i.e., with limited knee flexion) also generates significantly higher ground reaction forces than a soft configuration. A soft landing with large amounts of knee-joint flexion is more conducive to preventing injury than a stiff landing (9, 22, 24). Finally, increased internal/external rotation about the knee during landing is directly related to increased impact forces (16). When a landing is performed with the knees in a valgus or varus position, elevated impact forces are observed. Increased forces associated with increased jump height cannot be prevented. However, as demonstrated in the current study, landing strategy can be modified through short-term training that targets neurological adaptation related to motor unit recruitment, intermuscular communication between agonist and antagonist, and increased proprioceptive feedback. By targeting enhanced neuromuscular control, KLIP reduces impact forces and the rate of force development and also reduces stress to the neuromuscular system while landing. Thus, a knee injury is less likely after KLIP.

The present results are in agreement with previous research by Hewett et al., who studied the effect of a 6-week intensive training program of plyometrics, stretching, and strength training with a female high school volleyball team (16). Results demonstrated a reduction in peak impact forces and incidence of ACL injury. Another study by Hewett et al. examined the effects of the same training program on ACL injury incidence in a larger group of female high school athletes (15). The posttraining experimental group showed a reduction in the total number of serious knee injuries compared to the untrained group.

In contrast to the present study, the plyometric programs used by Hewett et al. was designed to improve landing mechanics and jump height (16). In addition to a reduction in peak impact forces, the experimental group in the study by Hewett et al. study increased vertical jump by 9.2%. It is difficult to determine if the improvements in landing mechanics are due to enhanced lower extremity control or lower extremity power. Also, the training groups in the Hewett et al. studies performed 3 different types of intervention (15, 16). Therefore, changes in landing strategies cannot be directly attributed to the plyometric training program alone. The current study only incorporated low-volume and intensity plyometric training. Thus, reductions in F_p and RFD can only be attributed to KLIP.

The training program employed in the current study was of low intensity and volume throughout the study duration. Further, the 20-minute, 2-day per week program can be integrated into regular athletic training programs with minimal risk of overtraining. The training regime employed by Hewett et al. involved 2 hours of training a day, 3 days a week (15, 16). For many recreational and collegiate athletes and teams, this represents an unrealistic time demand, and when feasible, requires intricate seasonal manipulation when incorporated into a team's periodized training. For individuals without a high level of physical fitness, high-intensity and volume plyometrics place a great deal of stress on the extremities and are associated with an increased injury risk (6, 17, 27).

Injuries to the ACL pose a major threat to women of all ages and athletic levels. The high incidence rate of injury has serious physical, mental, and economic implications. Neuromuscular differences in landing strategies appear to be responsible for the high injury rates in females. The findings of this study indicate that 9 weeks (18 sessions) of KLIP training is beneficial in reducing peak vertical-impact forces and rate of force development during landings.

Practical Applications

Prevention of injury is a major priority for all sport participants, coaches, athletic trainers, and parents. Results from this study demonstrate that a low volume and intensity plyometric training program (KLIP) can improve landing mechanics in a manner conducive to injury prevention. KLIP can be effectively incorporated into the individual's training program with minimal conflict. The low time demands and low intensity and volume of the program make it compatible for individuals with varying levels of conditioning and jumping experience. KLIP is a feasible and effective training strategy that may help to reduce the risk of noncontact ACL injuries.

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