Valgus Knee Motion during Landing in High School Female and Male Basketball Players

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ABSTRACT

FORD, K. R., G. D. MYER, and T. E. HEWETT. Valgus Knee Motion during Landing in High School Female and Male Basketball Players. *Med. Sci. Sports Exerc.*, Vol. 35, No. 10, pp. 1745–1750, 2003. **Purpose:** The purpose of this study was to utilize three-dimensional kinematic (motion) analysis to determine whether gender differences existed in knee valgus kinematics in high school basketball athletes when performing a landing maneuver. The hypothesis of this study was that female athletes would demonstrate greater valgus knee motion (ligament dominance) and greater side-to-side (leg dominance) differences in valgus knee angle at landing. These differences in valgus knee motion may be indicative of decreased dynamic knee joint control in female athletes. **Methods:** Eighty-one high school basketball players, 47 female and 34 male, volunteered to participate in this study. Valgus knee motion and varus-valgus angles during a drop vertical jump (DVJ) were calculated for each subject. The DVJ maneuver consisted of dropping off of a box, landing and immediately performing a maximum vertical jump. The first landing phase was used for the analysis. **Results:** Female athletes landed with greater total valgus knee motion and a greater maximum valgus knee angle than male athletes. Female athletes had significant differences between their dominant and nondominant side in maximum valgus knee angle. **Conclusion:** The absence of dynamic knee joint stability may be responsible for increased rates of knee injury in females but is not normally measured in athletes before participation. No method for accurate and practical screening and identification of athletes at increased risk of ACL injury is currently available to target those individuals that would benefit from neuromuscular training before sports participation. Prevention of female ACL injury from five times to equal the rate of males would allow tens of thousands of young females to avoid the potentially devastating effects of ACL injury on their athletic careers. **Key Words:** ACL INJURY, NEUROMUSCULAR CONTROL, MUSCULAR IMBALANCE, INJURY PREVENTION, GENDER DIFFERENCES, PREPARTICIPATION SCREENING

The knee is one of the most commonly injured areas of the body in female athletes. Injuries to the knee can account for up to 91% of season ending injuries and 94% of injuries requiring surgery in female basketball players (5). Season ending knee injuries can occur at a rate as high as 1 in 10 athletes annually at the intercollegiate level, which can account for 15,000 female athletes lost each year to athletic participation (16,25). Anterior cruciate ligament (ACL) ruptures are debilitating, often season-ending, knee injuries in female athletes that occur at a higher rate than in male athletes. In a study on the incidence of injury in collegiate basketball, Malone et al. (21) reported the ACL injury incidence was approximately sixfold higher in female than male players. Numerous studies have found a similar four- to sixfold higher incidence of knee injuries in females compared with males participating in jumping and cutting sports (5,8,11,16,18). This higher incidence of injury, combined with the dramatic increase in female participation that has occurred since the inception of Title IX in 1972, has led to a geometric increase in the number of ACL injuries in female athletes over the last three decades. In 2002, there were 452,728 female participants in high school basketball in the United States (26). At a rate of approximately 1 in 65 ACL injuries per participant annually, approximately 7000 ACL ruptures occur in high school female basketball players in the United States on an annual basis (16,30).

Significant attention has focused on ACL research over the past two decades resulting in more than 2000 scientific articles published outlining injury incidence, mechanism, surgical repair techniques, rehabilitation, and prevention of injury to this important knee ligament (9). The focus on ACL injury, especially on injury mechanism and prevention, is warranted considering that the cost of reconstructing and rehabilitating the ACL in these athletes at a conservative cost of $17,000 per patient would amount to $119 million annually spent on female high school basketball players alone (16). This is in addition to the traumatic effect to these individuals of potential loss of entire seasons of sports participation, possible scholarship funding, and significantly lowered academic performance (10).

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Submitted for publication January 2003.
Accepted for publication June 2003.

0195-9131/03/3510-1745
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/01.MSS.0000089346.85744.D9

ACL injuries result from either a contact or noncontact mechanisms. Noncontact ACL injuries account for more than two thirds of ACL injuries (3,12,16,23). The noncontact mechanism usually involves a deceleration before a change of direction or landing with the knee between 20° and full extension (3,23). Powell and Barber-Foss (27) found that rebounding the basketball was the cause of the majority of injures to female basketball players.

The potential mechanisms underlying the injury rate differences between genders can be categorized into three basic theories: anatomical, hormonal, and biomechanical. The risk of an ACL injury is likely multifactorial with no single causative factor being solely responsible for the increased rate. Anatomical risk factors that have been proposed include increased Q-angle, narrower femoral notch, and increased hypermobility or laxity in female athletes. Few, if any, anatomical variables, however, has been directly correlated with an increased risk of noncontact ACL injury (12). Decreased ligament strength or altered strength or muscle recruitment due to cyclic changes in female hormones may be possible contributors to the increased injury rates in female athletes (14). The experimental findings regarding the influence of hormones on injury risk are limited and remain controversial.

The third possible mechanism responsible for the gender differences in knee injuries is biomechanical or neuromuscular imbalances in female athletes. Three neuromuscular deficits related to biomechanical or neuromuscular coordination include ligament dominance, quadriceps dominance, and leg dominance (15). Andrews and Axe (1) first introduced the concept of ligament dominance whereby the lower extremity musculature does not adequately absorb the forces during a sports maneuver resulting in excessive loading of the knee ligaments, especially the ACL, which resists anterior tibial translation and knee valgus. Ligament dominance often results in high ground reaction forces, valgus knee moments, and excessive knee valgus motion. Quadriceps dominance is an imbalance between the recruitment patterns of the knee flexors and extensors. Females tend to rely on their quadriceps over their hamstrings to produce dynamic knee stability during jumping and landing activities (17,18). Leg dominance is an imbalance between muscular strength and recruitment patterns on opposite limbs, with one side often demonstrating greater dynamic control (17,19). Over-reliance on one limb can put greater stress on that knee, whereas the weaker side might not be able to effectively absorb the high forces associated with sporting activities.

Young athletes participating in high school sports are of particular interest due in part to the increase in sport participation at the high school level and the relative lack of literature related to mechanisms of injury at this age. With close to 3 million female high school sport participants and basketball players making up the largest percentage of these participants, additional research should focus on this population and identify specific mechanisms of injury within this group (26). The purpose of this study was to utilize three-dimensional kinematic (motion) analysis to determine whether gender differences existed in knee valgus kinematics in high school basketball athletes when performing a landing maneuver. The hypothesis of this study was that female athletes would demonstrate greater valgus knee motion (ligament dominance) and greater side-to-side (leg dominance) differences in valgus knee angle at landing. These differences in valgus knee motion may be indicative of decreased dynamic knee joint control in female athletes.

METHODS

Subjects. A total of 81 high school basketball players, 47 female (height = 168.7 ± 1.0 cm, weight = 62.9 ± 1.5 kg, age = 16.0 ± 0.2 yr) and 34 male (height = 179.8 ± 1.3 cm, weight = 69.7 ± 1.8 kg, age = 16.0 ± 0.2 yr), volunteered to participate in this study. The athletes were recruited from four Cincinnati, Ohio, area high schools just before the start of their competitive season. Informed written consent was obtained from all subjects and approved by the Cincinnati Children's Hospital Medical Center Institutional Review Board.

Experimental design. After the informed consent was obtained, height, weight, and dominant leg were assessed. The dominant leg was determined for each subject by asking which leg they would use to kick a ball as far as possible.

Each subject was instrumented with 23 retroreflective markers placed on the sacrum and bilaterally on the shoulder, ASIS, greater trochanter, mid thigh, medial and lateral knee, mid shank, medial and lateral ankle, and heel and toe (between second and third metatarsals). An additional marker on the left calf was also applied to offset the right and left side to aid the real time identification of markers during data collection. The motion analysis system consisted of eight digital cameras (Eagle cameras, Motion Analysis Corporation) connected through an Ethernet hub to the data collection computer (Dell Computer Corporation) and sampled at 240 Hz. Two force platforms (AMTI) were sampled at 1200 Hz and time synchronized to the motion analysis system. Data were collected with EvaRT (Version 3.21, Motion Analysis Corporation) and imported into KinTrak (Version 6.2, Motion Analysis Corporation) for data reduction and analysis. Before each data collection session, the motion analysis system was calibrated to manufacturer recommendations.

A static trial was collected to align the joint coordinate system to the laboratory. The subject was instructed to stand still and was aligned as closely with the laboratory coordinate system as possible. The medial markers were subsequently removed before the drop vertical jump (DVJ) trials. The DVJ consisted of subjects starting on top of a box (31 cm in height) with their feet positioned 35 cm apart (distance measured between toe markers). They were instructed to drop directly down off the box and immediately perform a maximum vertical jump and raising both arms as if they were jumping for a basketball rebound (24). The two force platforms were embedded into the floor and positioned 8 cm apart so that each foot would contact a different platform during the maneuver. The first contact on the platforms (i.e.,

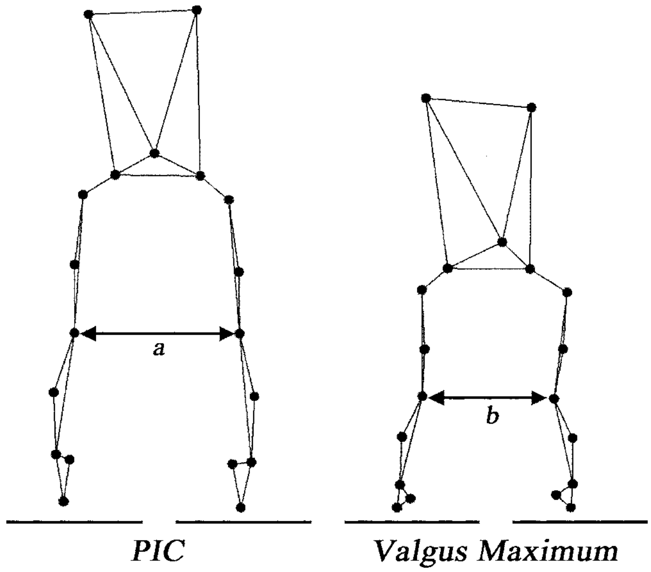


FIGURE 1—Calculation of valgus knee motion. PIC, frame before initial contact (A = coronal plane distance between right and left lateral knee markers). Valgus maximum: frame at maximum bilateral valgus (B = knee distance, see above). Total valgus knee motion is the difference between A and B.

the drop from the box) was used for analysis. Three successful trials were recorded for each subject.

Data analysis. The three-dimensional Cartesian marker trajectories from each trial were estimated using the DLT method and filtered through a low-pass Butterworth digital filter at a cutoff frequency (9 Hz) determined with residual analysis (29). Knee joint angles of varus-valgus for the right and left leg were calculated from an embedded joint coordinate system (13). Varus-valgus angle was reported as positive numbers representing valgus and negative numbers representing varus orientation. Vertical ground reaction force was used to identify the time at initial contact with the ground (IC) and at toe off from the jump (TO). Knee angle at IC and the maximum angle during stance (IC − TO) were recorded.

Bilateral valgus knee motion was calculated from the coronal plane distance between the right and left lateral knee markers during the DVJ (Fig. 1). The knee distance was recorded 0.03 s before IC (PIC) and then at the minimum knee distance during the stance phase (valgus maximum). The difference between PIC knee distance and valgus maximum knee distance was calculated as total valgus knee motion (centimeters). Total valgus knee motion was also normalized to height (total valgus knee motion/height) in order to account for any differences that might relate to the athlete's height.

Reliability measurements. Five subjects participated in a three-session between-day reliability assessment of the testing procedure. The sessions were held no more than 2 d apart and at approximately the same time of day. The reliability of knee distance at valgus maximum (ICC = 0.916) and total difference (ICC = 0.893) was high for the subjects tested.

TABLE 1. Valgus knee motion.

	Male (N = 34)	Female (N = 47)	
	Mean ± SE	Mean ± SE	P
Knee distance (cm)			
PIC	39.8 ± 0.6	39.3 ± 0.4	0.48
Valgus maximum	34.6 ± 0.8	32.1 ± 0.6	0.007**
Total difference	5.3 ± 0.5	7.3 ± 0.5	0.005**

Distance between the right and left knee is presented with mean and standard error of the mean for male and female subjects. The distance before initial contact (PIC) and at valgus maximum is shown with the total difference in centimeters.
** Significant differences ($P < 0.01$).

Statistical analysis. Statistical means and standard error of the mean for each variable were calculated for each subject. An ANOVA test was used to compare values between the male and female group and determine statistical significance ($P < 0.05$). To determine statistical significant differences between dominant and nondominant side, a paired t-test was used ($P < 0.05$). A Pearson correlation coefficient was measured to compare height and weight with valgus knee angle. Statistical analyses were conducted in SPSS (SPSS for Windows, Release 10.0.7).

RESULTS

The coronal plane distance between the right and left side lateral knee markers are presented in Table 1. Gender differences existed for valgus maximum (male 34.6 ± 0.8 cm, female 32.1 ± 0.6 cm, $P = 0.007$) and total valgus knee motion (male 5.3 ± 0.5 cm, female 7.3 ± 0.5 cm, $P = 0.005$) with females displaying more valgus knee motion. The knee distance before IC was not different between groups (male 39.8 ± 0.6 cm, female 39.3 ± 0.4 cm, $P = 0.48$). As expected, differences in height ($P < 0.001$) and weight ($P < 0.01$) between male and females were found. Statistically significant results of total valgus knee motion were also found between male and female groups when normalized to height (male 0.029 ± 0.003 cm/height, female 0.043 ± 0.003 cm/height, $P = 0.001$)

Knee valgus angle (average of the three trials) for the dominant side and standard error for male and female athletes during DVJ stance is displayed in Figure 2. Female subjects displayed a significantly higher maximum valgus knee angle than the male subjects on their dominant side

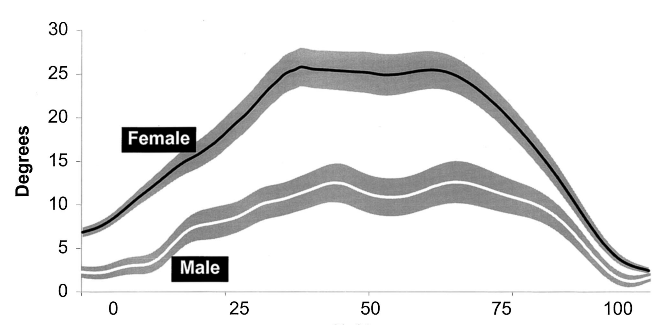
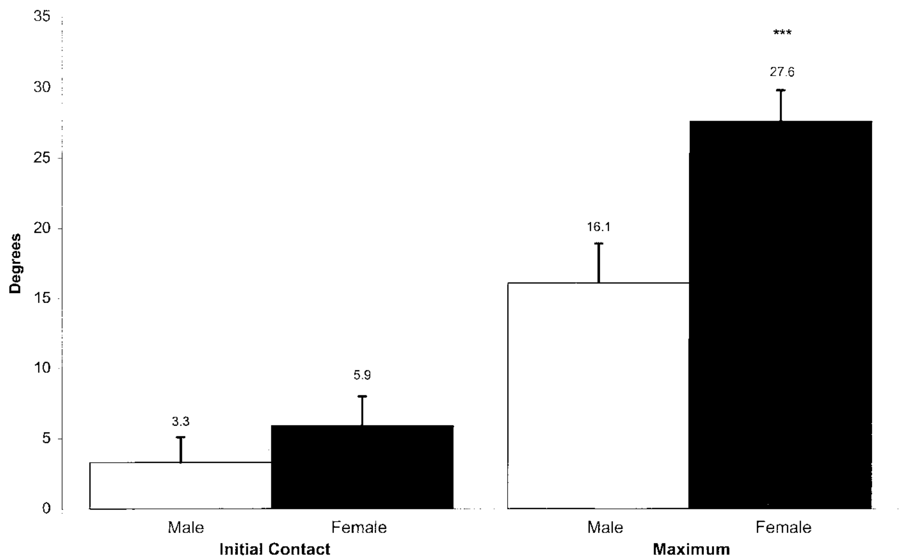


FIGURE 2—Average valgus knee angle during stance phase for male (*white*) and female (*black*) difference with standard error of the mean (*gray*).

FIGURE 3—Valgus knee angle at initial contact and maximum angle during stance in male and female athletes (***significant differences ($P < 0.001$)).



(male 16.1 ± 2.1°, female 27.6 ± 2.2°, $P < 0.001$) (Fig. 3). There was a trend toward a higher valgus angle on their dominant side at IC in the female athletes compared with the males; however, it was not a statistically significant difference ($P = 0.055$). There was not a significant correlation between knee valgus angle and either height (initial contact R = 0.01, $P = 0.92$; maximum R = −0.06, $P = 0.58$) or weight (initial contact R = 0.09, $P = 0.40$; maximum R = −0.03, $P = 0.82$)

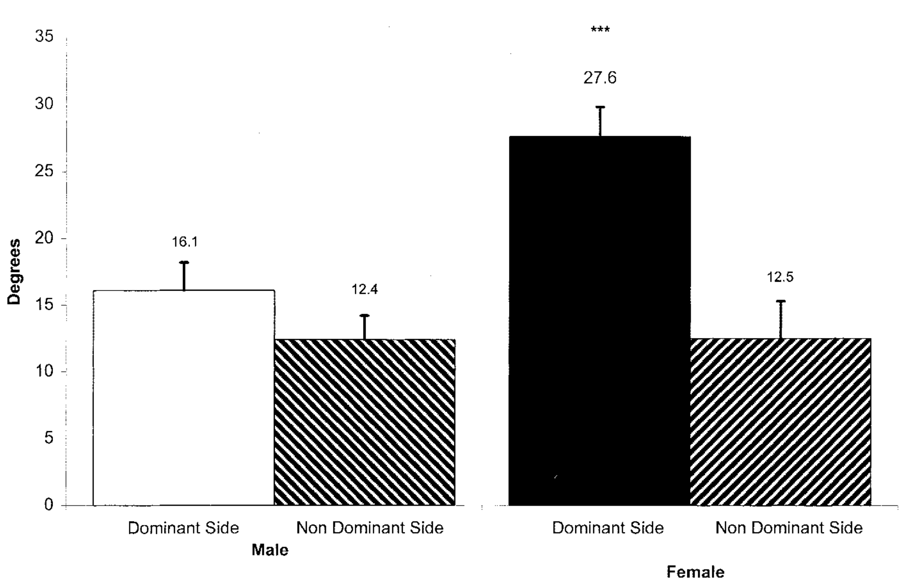
Side-to-side comparison of valgus knee angle maximum show statistically significant differences in female (dominant side 27.6 ± 2.2°, nondominant side 12.5 ± 2.8°, $P < 0.001$) but not male athletes (dominant side 16.1 ± 2.1°, nondominant side 12.4 ± 1.8°, $P = 0.127$) (Fig. 4). There were no statistically significant differences between the normalized vertical ground reaction force and absolute duration of stance phase between male and female groups or between the dominant and nondominant side within groups.

DISCUSSION

The purpose of this study was to determine gender-related differences in knee valgus motion in high school athletes. Identification of these differences may help determine why female high school athletes display a higher incidence of noncontact ACL injuries compared with males. Female subjects in this study showed what has previously been described as ligament dominance (1,15). Ligament dominance relates to the inability of an athlete's musculature to control torque on the joints of the lower extremity, especially the knee joint, during a sports maneuver. Ligament dominance often results in excessive knee valgus motion or abnormal forces. Increased knee valgus motion was apparent in female athletes compared to males measured with two different techniques.

The first method for measuring valgus knee motion involved calculating the distance between the right and left knee after dropping from a box before performing a maxi-

FIGURE 4—Valgus knee angle maximum, side-to-side comparison. Comparison of valgus knee angle maximum between dominant and nondominant side (***significant differences ($P < 0.001$)).



mum vertical jump. Females demonstrated more valgus knee motion at the point of maximum valgus. This was apparent in the calculation of total valgus motion as well with females exhibiting more total valgus knee motion. Athletes with increased valgus knee motion likely exhibit decreased joint control in the coronal planes and may be at an increased risk of knee injury.

Similar techniques for calculating valgus knee motion have previously been obtained with standard two-dimensional video analysis (24). Myer et al. (24) showed related gender differences in high school basketball players of approximately 3 cm of total valgus knee motion. We are currently investigating the relationship between a two-dimensional field test for knee motion and the method described in this paper. The correlation between these two methods is high in pilot studies ($R = 0.94$, $P < 0.001$, $N = 64$). A two-dimensional video method would allow on-site screening of large numbers of athletes and identify those that have excessive valgus knee motion.

The second method employed for identifying ligament dominance was the analyses of varus-valgus angles during the DVJ. The female athletes displayed greater maximum valgus angles during the stance phase of their dominant side compared to the male athletes. The statistically significant mean difference of over 11° between groups is a considerable amount. This represents a key neuromuscular gender difference in the performance of a sport specific movement like a basketball rebound. Malinzak et al. (20) found differences in valgus knee angles during side-step and cross-over cutting between male and female recreational athletes.

The observed increase in motion at the knee (valgus knee motion and valgus angle) suggests altered muscular control of the lower extremity in the coronal plane. This likely reflects changes in contraction patterns of the adductors and abductors of the knee, primarily the knee flexors, the hamstrings and gastrocnemius, which possess tendons that cross both the medial and lateral sides of the knee joint. Decreased neuromuscular control of the knee joint reduces knee joint stiffness and increased risk to the ligament. Muscular contraction can decrease both the valgus and varus laxity of the knee threefold. Chappell et al. (6) have shown differences in valgus moments at the knee in female and male athletes, with females displaying greater valgus force during the landing phase of a vertical jump maneuver. It has been demonstrated that strain on the ACL was greatest during eccentric quadriceps activation combined with a valgus or varus force at the knee (2). This combination of forces is present in individuals that perform poorly during the drop vertical jump testing. Subjects with high valgus motion and valgus angles are likely putting high strain on their ACL.

Female athletes in this study showed significant side-to-side differences in maximum knee valgus angle compared with males. The dominant leg had significantly greater valgus knee angles than the nondominant leg in the female players. The imbalance in side-to-side measurements is indicative of leg dominance, which may predispose female athletes to noncontact ACL injuries (15). Side-to-side imbalances in neuromuscular strength, flexibility, and coordination have been shown to be important predictors of increased injury risk (16,17,19). Limb dominance may potentially place both limbs at an increased risk of ACL injury. The weaker limb may be compromised in its ability to manage even average forces and torques, whereas the stronger limb may experience exceptionally high forces and torques due to increased dependence and increased loading on that side in high-force situations. Hewett et al. (17) demonstrated that females had significant side-to-side differences in hamstrings peak torque and hamstrings to quadriceps peak torque ratios before participating in a neuromuscular training program. Upon completion of the training program, these side-to-side imbalances were diminished.

The recent data support that dynamic neuromuscular training should be utilized in female athletes to decrease the incidence of ACL injuries (4,16). Hewett et al. (17) demonstrated significant decreases in landing forces and valgus and varus torques at the knee, significant increases in hamstrings power, and correction of hamstrings strength imbalances in a similar group of female high school athletes after neuromuscular training. High landing forces and resultant knee torques have been reported to be related to knee injury (7). In a second study, Hewett et al. (16) prospectively evaluated the effect of neuromuscular training on knee injury in approximately 1300 high school athletes. Two groups of females, one trained before sports participation, the other not trained, and a group of untrained males were followed throughout the high school soccer, volleyball, and basketball seasons. In this study, neuromuscular training decreased the incidence of serious knee injury 62% in the high-risk female sports population, down to levels statistically similar to male levels.

The potential benefit of injury prevention training is wide ranging, and the entire population of female athletes would likely benefit from preparticipation training. However, it would appear that those who demonstrate poor dynamic knee stability might benefit more from training. The next step should be to develop methods to further identify athletes that might be at risk of injury. The absence of dynamic knee joint stability may be responsible for the increased rates of knee injury in females (15) but is not normally measured in athletes before sports participation. Standard preparticipation physicals assess static measures of joint stability. Few if any dynamic measures are assessed during these exams, and plans for intervention are rarely implemented. Though static musculoskeletal disorders are observed during preparticipation examination in approximately 10% of examined athletes (22), intervention occurs in 1–3% (28). No method for the accurate and practical screening and identification of athletes at increased risk of ACL injury is currently available. Valgus motion assessment before participation may provide at least a partial answer to this dilemma.

We conclude that gender differences in valgus knee motion exist in high school athletes during jumping and landing. This difference may be related to the increased incidence of noncontact ACL injuries in female athletes. Neuromuscular training programs should be designed to specifically address excessive valgus knee motion and side-to-side imbalances in hamstrings torque and hip abductor strength. Correction of neuromuscular imbalances is important for both the optimal biomechanics of athletic movements and reduction of knee injury incidence. Further study on the effects of neuromuscular training is important for the advancement of injury prevention and safe participation in athletics.

Advances in the prevention of ACL injuries in young female athletes, who are at a four- to sixfold increased risk of ACL injury relative to males, are necessary for their continued safe participation in sports. Sports medicine professionals need to identify the female athletes who are at high risk for ACL injury. Screening tests should be used to identify athletes at high risk for ACL injuries. It is likely that a significant proportion of the female sports population will demonstrate decreased dynamic knee stability and will require intervention. Prevention of female ACL injury from five times to equal the rate of males would allow tens of thousands of young females to continue the health benefits of sports participation and to avoid the long-term complications of osteoarthritis, which occurs with a 10-fold greater incidence than occurs in the uninjured population. With the rapidly increasing number of female participants in high-risk sports and the rapidly growing number of participants each year, even higher numbers of future injuries can be avoided in this high-risk population.

This work was supported by Cincinnati Children's Hospital Research Foundation and the Division of Molecular Cardiovascular Biology.

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