Gender Differences in Hip Joint Kinematics and Kinetics During Side-Step Cutting Maneuver

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Objective: Based on the recent suggestion that proximal hip control may be related to a predisposition to anterior cruciate ligament injury, our purpose was to identify gender differences in hip mechanics between female athletes who previously demonstrated greater knee valgus moments and their male counterparts.

Design: Descriptive laboratory study.

Setting: Testing was conducted in a biomechanics research laboratory.

Participants: Thirty collegiate soccer players (15 women and 15 men) participated in this study. All subjects were healthy with no current complaints of lower extremity injury.

Main Outcome Measurements: Three-dimensional hip joint kinematics and kinetics were collected while subjects performed a side-step cutting maneuver. Gender differences in hip mechanics were compared using independent sample *t* tests.

Results: Compared with male athletes, female athletes demonstrated significantly greater hip internal rotation and decreased hip flexion. In addition, female athletes demonstrated significantly greater hip adductor moments as well as decreased hip extensor moments.

Conclusion: Overall, it appeared that female athletes moved into greater hip internal rotation and used less sagittal plane hip motion during the early deceleration phase of the cutting maneuver. The findings of this investigation support the premise that altered hip kinematics and kinetics may influence loading at the knee. Future studies are needed to further explore the impact of these differences on knee loading and to ascertain the underlying causes.

Key Words: anterior cruciate ligament (ACL), proximal control, knee valgus

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INTRODUCTION

Female athletes participating in cutting and jumping sports have been reported to have a 4 to 6 times greater chance of tearing their anterior cruciate ligament (ACL) than their male counterparts.[1,2] Most ACL injuries occur during a noncontact incident as the athlete is decelerating and/or changing direction.[3,4] It has been theorized that the disproportionate number of ACL injuries in female athletes is due to gender-related differences in the performance of athletic activities.[5–11]

It is understood that noncontact ACL injuries most frequently occur during some form of cutting or landing maneuver; therefore, studies have examined gender differences in lower extremity movement patterns while performing such activities. Investigations of gender differences in knee joint kinematics have revealed that, when compared with male athletes, female athletes demonstrate decreased knee flexion and increased valgus during landing,[5,6,10,12] cutting,[6–8] and running.[6,13] Hewett et al[14] have found both knee valgus motion and knee valgus moments to be predictors of ACL injury. Taken together, the knee joint kinematics exhibited by female athletes are thought to place them at a greater risk of ACL injury. This premise is supported by the in vitro work of Markolf et al,[15] which identified that a valgus moment placed on a relatively extended knee (ie, 0 to 40 degrees) increases the strain on the ACL.

It has been suggested that the deleterious knee joint kinematic patterns exhibited by female athletes may be related to poor proximal control (eg, hip weakness). Leetun et al[16] found gender differences in hip strength and proposed that this proximal weakness may partially explain the gender bias in ACL injuries among female athletes. As a result of this suggestion, investigators have begun to broaden their focus and examine the influence of the hip on lower extremity mechanics.

Studies have shown that female athletes demonstrate a greater reliance on the frontal and transverse planes at the hip when performing dynamic activities. For example, female athletes have been shown to exhibit greater hip adduction and internal rotation during walking,[17] running,[13] and landing.[12] Pollard et al[9] examined gender differences in hip kinematics and kinetics during cutting and found the only difference in hip mechanics to be relatively less hip abduction in female athletes. Although these results are of interest, the female athletes in this investigation did not exhibit the potentially harmful knee pattern of increased valgus angles or valgus moments that are thought to predispose female athletes to ACL injury.

While it is evident that female athletes consistently demonstrate increased frontal plane (ie, valgus) and decreased sagittal plane motions at the knee, the link between proximal

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control strategies and abnormal knee joint loading remains unclear. Since frontal and transverse plane knee motion and moments are most likely influenced by hip mechanics and largely controlled by passive knee structures, abnormal proximal movement patterns may perhaps place female athletes at a higher risk for ACL injury.

In a previous study,[11] we demonstrated that gender differences in knee valgus moments existed in collegiate soccer players. On average, female athletes demonstrated significantly greater knee valgus moments during early deceleration as compared with male athletes (0.431 $\pm$ 0.5 Nm/kg vs 0.006 $\pm$ 0.3 Nm/kg). The recent suggestion that proximal hip control may be related to a predisposition to ACL injury warranted the evaluation of hip joint kinematics and kinetics in this cohort of athletes who exhibited differences in knee valgus moments. Therefore, the purpose of this study was to identify gender differences in hip mechanics between these female soccer athletes who previously demonstrated greater knee valgus moments as compared with male athletes. We hypothesized that when compared with male athletes, female athletes would demonstrate greater average hip adduction and internal rotation as well as decreased hip flexion during the early deceleration phase of a side-step cutting maneuver. In addition, it was hypothesized that female athletes would demonstrate greater peak hip frontal and transverse plane moments as well as decreased hip sagittal plane moments during the early deceleration phase of a side-step cutting maneuver.

MATERIALS AND METHODS

Subjects

The subjects group was comprised of 15 female and 15 male collegiate soccer players that were NCAA Division I or II athletes with at least 1 year of collegiate experience (Table 1). This sample population is considered a sample of convenience because subjects were recruited to participate as volunteers from local surrounding colleges. The average years of soccer experience for the female athletes in this study was 13.4 (SD, 2.2) years and the male athletes was 12.4 (SD, 3.0) years.

All subjects were healthy with no current complaints of lower extremity injury. Subjects were excluded from the study if they reported any of the following: (1) history of ACL injury or repair; (2) previous injury that resulted in ligamentous laxity at the ankle, hip, or knee; (3) presence of any medical or neurologic condition that would impair their ability to perform a side-step cutting task.

TABLE 1. Subject Characteristics

	Female Athletes Mean (SD)	Male Athletes Mean (SD)
Subjects, n	15	15
Age, yr	19.4 (1.5)	19.6 (1.9)
Height, cm	167.4 (8.0)	179.1 (6.0)
Mass, kg	65.9 (7.0)	74.2 (7.0)

Instrumentation

Kinematic data were collected using a Vicon six-camera, three-dimensional motion analysis system (Oxford Metrics, Oxford, England) at a sampling frequency of 120 Hz. The cameras were interfaced to a microcomputer and placed around a force platform embedded within the floor (Advanced Mechanical Technologies, Inc., Newton, MA). The force platform (2400 Hz) was interfaced to the same microcomputer that was used for kinematic data collection via an analog-to-digital converter. This interface allowed for synchronization of kinematic and kinetic data.

Procedures

All testing took place at the Musculoskeletal Biomechanics Research Laboratory at the University of Southern California. Before participation, all procedures were explained to each subject, and informed consent was obtained as approved by the Institutional Review Board for the University of Southern California Health Sciences Campus.

Before kinematic and kinetic data collection, height and mass were measured, and subjects were fitted with the same style of cross-training shoe (New Balance, Boston, MA). Once the subject had donned the shoes, reflective markers (25 mm spheres) were placed on bilateral anterior superior iliac spines, posterior superior iliac spines, lateral epicondyles of the knee, lateral malleoli, calcaneus, and bases of the fifth metatarsal. The thigh and calf markers were mounted on 5 cm wands and secured on the thigh and shank with elastic bands. The foot markers were placed on the shoes, and the same individual placed the markers for all subjects.

Consistent with the work of McLean et al[7] subjects were instructed to run 5 m at a speed of 5.5 to 7.0 m/s before contacting their right foot on the force plate and then change direction to the left (Figure 1). Cones placed at 35 degrees and 55 degrees from the original direction of progression were used to direct the subjects to cut at an angle of 45 degrees (Figure 1). Approach speed was calculated with the use of a photoelectric switch and force plate contact. Subjects completed 4 successful trials, and a trial was deemed successful if: (a) the subject's right foot came into contact with the force platform, (b) the subject remained within the pathway designated by the cones, and (c) the required approach speed was maintained. The subjects were allowed 3 to 5 practice trials in order to become familiar with the procedures and instrumentation.

Data Analyses

Vicon Clinical Manager (VCM) software (Oxford Metrics, Oxford, England) was used to quantify lower extremity joint angles and moments in the sagittal, frontal, and transverse planes. Coordinate data were filtered using a Woltering quintic spline filter with a predicted mean square error of 20 mm. All kinetic data were normalized to body mass, and net joint moments were calculated with standard inverse dynamics equations. The angle and moment data were linearly interpolated to 101 data points, and each point represented 1% of the stance phase (0% to 100%). Ensemble curves of 4 acceptable trials were created. Joint kinetic data were reported as net muscle moments (ie, internal moments).

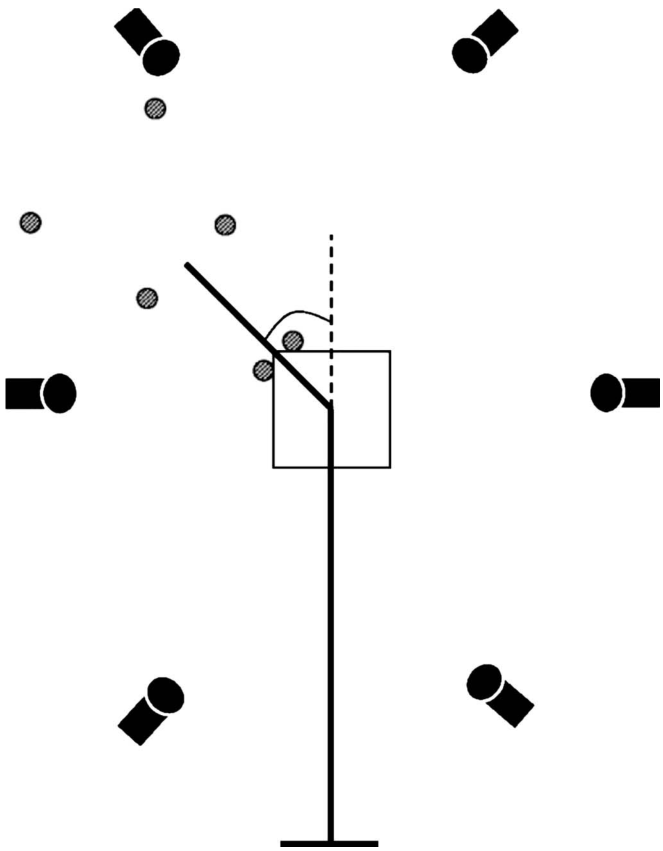

FIGURE 1. Runway, cutting, and camera set-up.

For the purpose of this study, only the early deceleration phase of the cutting maneuver was considered, as this is the time in which the majority of noncontact ACL injuries have been reported to occur.[3] In addition, this is the phase in which gender differences in knee valgus moments have been identified.[11] Early deceleration was defined as the first 20% of the stance phase. The evaluated dependent variables consisted of average hip internal rotation, adduction and flexion angles, as well as peak hip external rotator, adductor, and extensor moments during early deceleration.

Statistical Analyses

To determine whether average hip joint kinematics and peak hip joint moments differed between genders, independent sample t tests were performed. Statistical analyses were performed using SPSS statistical software (Chicago, IL). Significance levels were set at $P < 0.05$.

RESULTS

Average three-dimensional hip joint angles and peak moments for male and female athletes during the early deceleration phase of a side-step cutting maneuver are presented in Figure 2.

Kinematics

When compared with male athletes, female athletes demonstrated significantly greater hip internal rotation (7.7 degrees vs −1.0 degrees; $t = 2.89$; $P = 0.01$) during the early deceleration phase of the side-step cutting maneuver. During early deceleration, female athletes also exhibited decreased hip flexion (49.3 degrees vs 54.0 degrees; $t = 2.32$; $P = 0.05$) as compared with male athletes. There were no gender differences in hip frontal plane motion, as all subjects were in an abducted position during the early deceleration phase.

Kinetics

Female athletes demonstrated greater hip adductor moments (−1.69 Nm/kg vs −0.87 Nm/kg; $t = 2.15$; $P = 0.04$) during early deceleration as compared with male athletes. In addition, female athletes exhibited decreased hip extensor moments (5.36 Nm/kg vs 6.67 Nm/kg; $t = 2.20$; $P = 0.04$). There were no gender differences in hip external rotator moments.

DISCUSSION

Our results support the premise that gender differences in hip kinematics and kinetics exist during the performance of a side-step cutting maneuver. This group of female athletes who have previously demonstrated greater knee valgus moments when compared with male athletes[11] employed different movement patterns at the hip in order to successfully perform the cutting maneuver. In particular, female athletes demonstrated more of a reliance on the frontal and transverse planes as opposed to the sagittal plane. This was supported by greater hip internal rotation and decreased hip flexion exhibited by female athletes during the early deceleration phase of the cutting maneuver. In addition, female athletes demonstrated greater hip adductor moments and decreased hip extensor moments during this phase.

This pattern of increased hip internal rotation is consistent with previous studies evaluating gender differences in hip kinematics during various activities such as walking,[17] overground running,[13] and single-leg landing.[12] On the basis of these findings, it has been suggested that increased hip internal rotation during functional activities may result in altered alignment of the lower extremity leading to a predisposition to ACL injury. This argument is supported by qualitative analysis of noncontact ACL injuries from video tapes that have described a position of hip internal rotation.[3]

While the female athletes moved into greater degrees of hip internal rotation, they also demonstrated decreased hip motion in the sagittal plane. This finding is similar to previous studies evaluating gender differences in landing[16] and modified side-step cutting.[8] In addition to the observed decrease in hip flexion angle, female athletes also exhibited decreased hip extensor moments. This suggests that male athletes were better able to engage the hip extensors in order to control the deceleration phase of the cutting maneuver in the sagittal plane. The increased use of hip extensors (ie, gluteus maximus) by the male athletes may have contributed to the observed gender differences in hip internal rotation, since a known action of the gluteus maximus is hip external rotation.[18] It is possible that the female athletes in the current study lacked the strength needed to decelerate in the sagittal plane, resulting in an alternate proximal control strategy that exploited the transverse and frontal planes. This concept is supported by the work of Leetun et al[16]

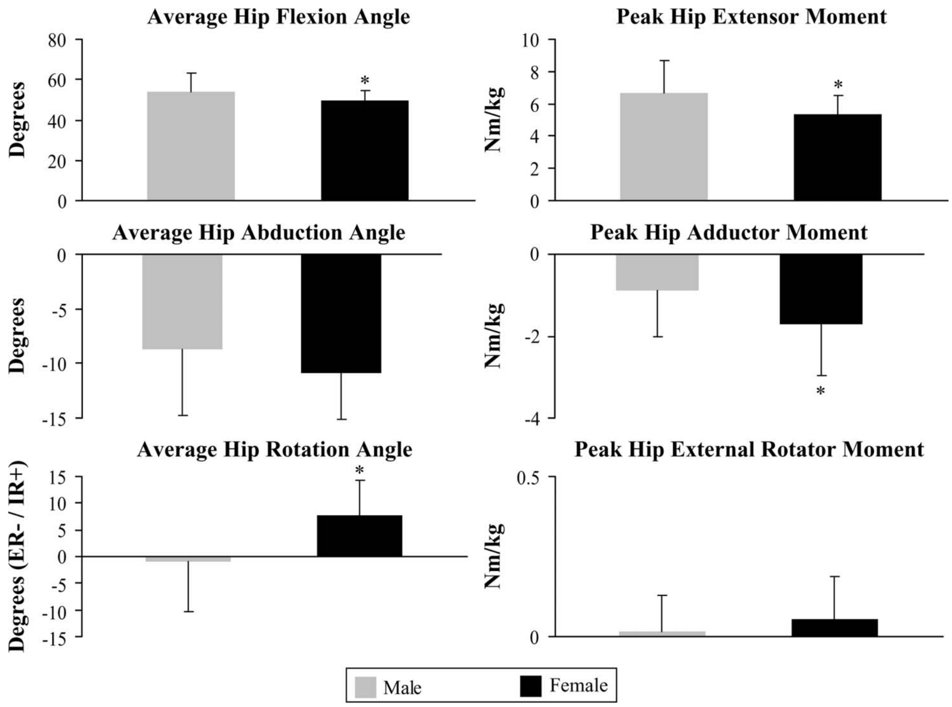

FIGURE 2. Three-dimensional hip joint kinematics and kinetics during the early deceleration phase of a side-step cutting maneuver.

who found decreased hip strength in female collegiate athletes as compared with male athletes and suggested that this weakness may permit lower extremity positioning frequently associated with noncontact injuries.

No differences were observed in frontal plane hip joint kinematics. This result was initially surprising because previous studies have found that female athletes demonstrate greater hip adduction during running[13] and relatively less hip

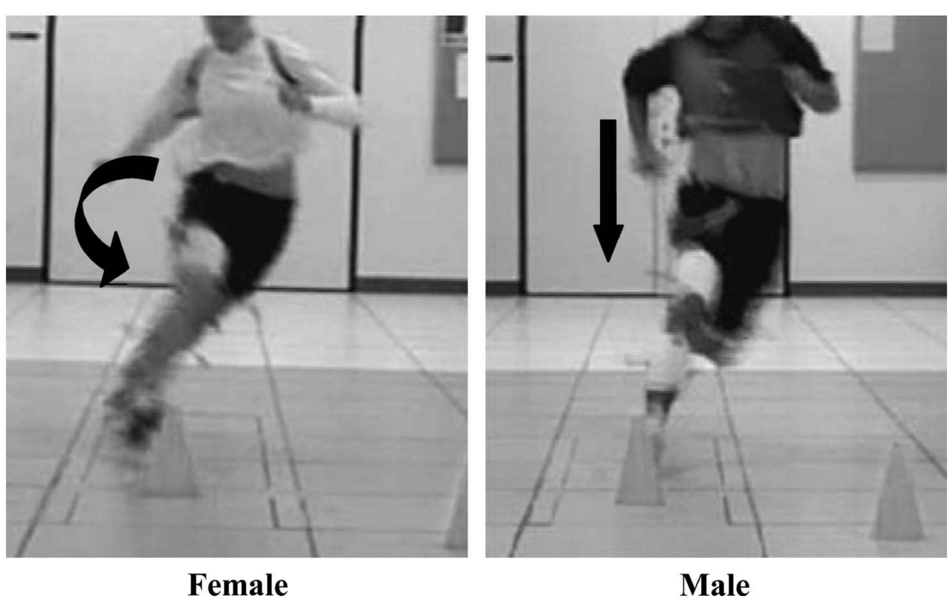

FIGURE 3. An example of how female athletes had a tendency to lean their trunk over their stance leg when performing the cutting maneuver as compared with male athletes. While the current study did not quantify trunk kinematics, future investigation is warranted.

abduction during cutting.[8,9] When evaluating frontal plane hip kinematics and kinetics, all subjects were in an abducted position and demonstrated an adductor moment during the early deceleration phase. However, as compared with male athletes, female athletes exhibited a greater peak hip adductor moment. In the absence of gender differences in frontal plane hip kinematics, it is suspected that this increased adductor moment may be the result of a trunk lean over the stance limb, which would shift their center of mass laterally thereby increasing their adductor moment. Although we did not quantify trunk motion, we subjectively observed that female athletes appeared to demonstrate this pattern of trunk lean over their stance limb as portrayed in Figure 3. Future studies are needed to examine the influence of trunk motion and proximal strength on lower extremity mechanics.

While differences in lower extremity kinematics and kinetics were apparent, a potential limitation of the study may have been the lack of adjustments for multiple *t* tests. An additional limitation of the study was that it only included soccer players of a specific age group. Future studies are needed to examine the influence of gender and age on hip mechanics during cutting and landing tasks in athletes that participate in sports such as volleyball and basketball.

In summary, female athletes demonstrated altered hip joint kinematics and kinetics as compared with male athletes. The findings of this investigation support the premise that proximal control may influence the incidence of ACL injuries among female athletes. Future studies are needed to further explore the impact of these differences on knee loading and to ascertain the underlying causes. For example, it should be determined if the proximal control strategies exhibited by female athletes are due to existing musculature weakness or if they were developed at an early age and maintained throughout their years of athletic participation.

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