CLINICAL ORTHOPAEDICS AND RELATED RESEARCH
Number 401, pp. 162–169

Gender Differences in Strength and Lower Extremity Kinematics During Landing

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This study evaluated kinematic, vertical ground reaction forces, and strength variables in healthy collegiate female basketball, volleyball, and soccer players compared with matched male subjects. Thirty athletes did single-leg landing and forward hop tasks. An electromagnetic tracking device synchronized with a force plate provided kinematic data and vertical ground reaction force data, respectively. Maximum angular displacement and time to maximum angular displacement kinematic variables were calculated for hip flexion, abduction, rotation, knee flexion, and lower leg rotation. Vertical ground reaction force data normalized to body mass provided impulse, maximum force, time to maximum force, and stabilization time variables. An isokinetic device measured quadriceps and hamstring peak torque to body mass at 60°/second. With both tasks, females had significantly less knee flexion and lower leg internal rotation maximum angular displacement, and less knee flexion time to maximum angular displacement than males. For the single-leg land, females had significantly more hip internal rotation maximum angular displacement, and less lower leg internal rotation time to maximum angular displacement than males. For the forward hop, females had significantly more hip rotation time to maximum angular displacement than males. Females also had significantly less peak torque to body mass for the quadriceps and hamstrings than males. Weaker thigh musculature may be related to the abrupt stiffening of the knee and lower leg on landing in females.

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Received: May 16, 2001.

Revised: September 18, 2001; October 23, 2001.

Accepted: November 16, 2001.

The rate of injury to the anterior cruciate ligament in the population in the United States exceeds one in every 3000 persons.[25] Of these physically active individuals, females sustain anterior cruciate ligament ruptures two-to-eight times more frequently than their male counterparts with risk of injury increasing with participation in soccer and basketball.[1,10,11,18,20,25] Many noncontact mechanisms of injury have been proposed to be responsible for this disproportionate injury rate.[3,12]

Numerous studies have focused on neuromuscular and biomechanical variables.[4–7,13,15,17,22,26,31,33] Although these studies have shown gender-related differences, there is a lack of consistency in study designs and variables reported. From a neuromuscular perspective, females have been identified as being quadriceps dominant, where the quadriceps are the first muscle to activate in response to injury mechanism perturbations[15] and selective athletic maneuvers.[4] This tendency may result in excessive stress placed on the anterior cruciate ligament because an unopposed quadriceps contraction will displace the tibia anteriorly.[34] Additionally, one study found females to have reduced proprioception,[29] which may allow excessive joint movement before dynamic stabilizers can effectively protect the joint. Two biomechanical studies focused on knee flexion angles at ground contact, suggesting that there is a relationship between this angle and the risk for anterior cruciate ligament injury.[4,19] Another study found that high ground reaction forces are gender-specific accompanying landing in female athletes.[13]

Although the above studies reported valuable findings and began to establish a gender-related profile, they lack data concerning motion of the lower extremity that occurs after ground contact that may provide additional information about fundamental mechanisms contributing to the risk of anterior cruciate ligament injuries. Of particular concern is the effectiveness of the lower extremity to dissipate the forces generated during landing. If impact force at the knee is applied during a short time, and without accommodating joint movement, the body has less of an opportunity to attenuate forces. To date, a few studies[7,8,31] have focused on the maximum angular displacement or the difference between the ground contact and peak angles; however, a gender comparison was not conducted. If the amount of time to maximum angular displacement is maximal, and if the maximum angular displacement is large, then impact forces will be attenuated. Theoretically, this biomechanical pattern should allow optimal conditions to prevent injury.

The current study evaluated lower extremity kinematic patterns, vertical ground reaction forces, and muscle strength in collegiate female basketball, volleyball, and soccer players compared with matched recreational male athletes.

MATERIALS AND METHODS

Subjects and Research Design

Fifteen female Division I basketball, volleyball, and soccer athletes (age, 19.3 ± 1.2 years; height, 174.5 ± 6.8 cm; weight, 68.0 ± 9.0 kg) and 15 matched, according to age and activity level, male recreational athletes who previously had played organized basketball or soccer (age, 21.26 ± 1.55 years; height, 177.62 ± 6.34 cm; weight, 75.45 ± 8.53 kg) participated in this study. All subjects were injury-free, signed informed consent, and attended one testing session. During this session, each subject completed two landing tasks and a strength assessment.

Kinematic data were collected using the Motion Monitor Motion Analysis System (Innovative Sports Training, Chicago, IL) electromagnetic tracking device. Four electromagnetic motion analysis sensors were secured to subjects using prefabricated neoprene cuffs with clips to the desired limbs. Sensors were placed over the upper thorax, sacrum, lateral thigh, and lateral lower leg to evaluate hip flexion, rotation and abduction, knee flexion, and lower leg rotation at 100 Hz. Maximum angular displacement and time to maximum angular displacement were calculated for the aforementioned joint motions. Maximum angular displacement was defined as the difference between the ground contact angle and the peak angle attained after ground contact. The time to maximum angular displacement was defined as the time to achieve maximum angular displacement from ground contact.

Vertical ground reaction forces were assessed using a Bertec force plate (Bertec Corporation, Columbus, OH) that was synchronized with the motion monitor. Vertical ground reaction forces were sampled at 1000 Hz. Landing forces, specifically maximum vertical force and time to maximum vertical force, were evaluated at ground contact, which was defined as 1% of body mass. The vertical ground reaction force also was used to measure the time to maximum force and impulse. Impulse was calculated and defined as the area under the curve in a time interval from which the vertical ground reaction force exceeds 10% of the subjects' body mass to 0.1 second after ground contact. A sequential estimation using an algorithm defined by Colby et al[5] was used to determine the stabilization time of the vertical ground reaction force (Fz), mediolateral force (Fx), and anteroposterior force (Fy). Stabilization time is calculated by the interval from ground contact to when the vertical reaction force is reduced to 5% of the subject's body weight.

The landing task order was counterbalanced between subjects. The first subject was assigned randomly to first do single-leg landing, followed by the forward hop. The order of performance of the landing tasks then was alternated between subjects. Both landing tasks began with subjects standing with their hands on their hips and balancing on the dominant leg. The dominant leg was defined as the leg with which subjects prefer to kick a ball. The verbal cue of jump signaled the subjects to hop onto the X marked on the force plate. For single-leg landing (Fig 1), subjects hopped off a 20 cm platform. The platform was placed 11 cm from the back edge of a force plate.[5,23] During the forward hop task (Fig 2), subjects started at a distance of 45% of their height away from the X marked on the force plate. An obstacle was placed equidistant between the starting line and X.[5] Subjects did three practice trials followed by four test trials of each task. An investigator was present at all times to prevent falling or other potential adverse events.

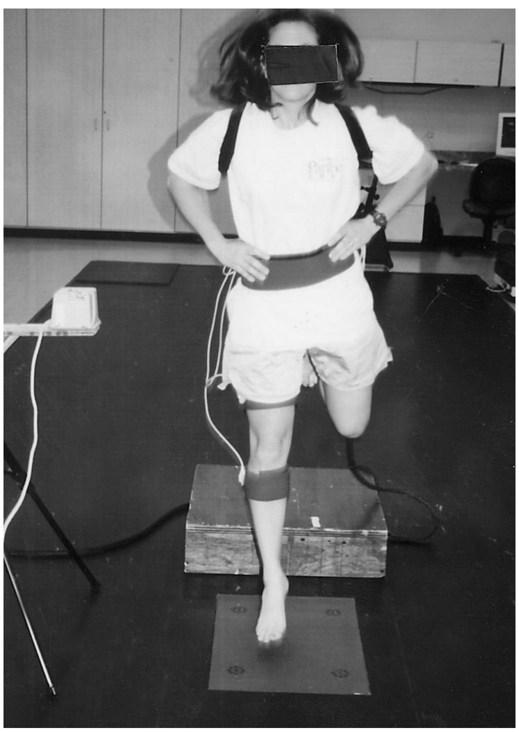

Fig 1. The subject is showing the single-leg landing task.

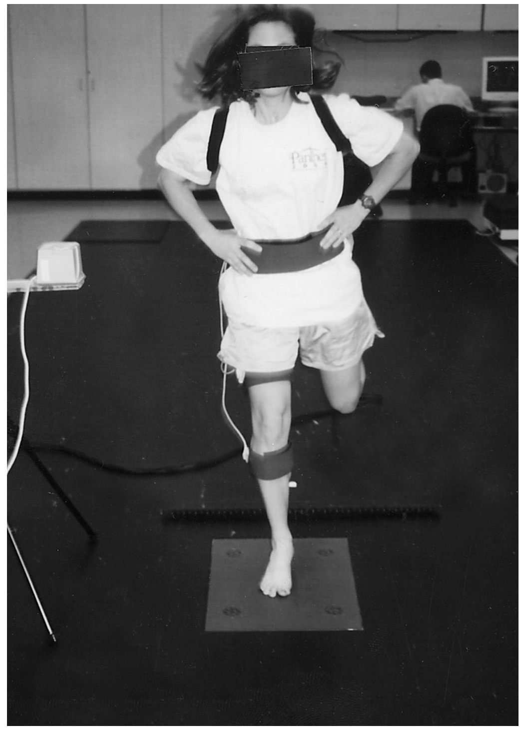

Fig 2. The subject is showing the forward hop landing task.

Isokinetic Assessment

Isokinetic strength data were recorded with the Biodex System III Dynamometer (Biodex Medical Inc, Shirley, NY) to assess peak torque to body weight of the quadriceps and hamstrings. Torque values were adjusted automatically for gravity by the Biodex Advantage Software v. 3.2 (Biodex Medical Inc). Calibration of the Biodex dynamometer was done according to the specifications outlined in the manufacturer's service manual.

For knee testing, subjects sat in a comfortable upright position on the Biodex dynamometer chair and were secured using thigh, pelvic, and torso straps to minimize extraneous body movements and momentum. The lateral femoral condyle was used as the bony landmark for aligning the axis of rotation of the knee with the axis of rotation of the dynamometer. Practice trials of three submaximal and three maximal repetitions preceded the test to ensure unrestricted movement through the range of motion and subject familiarization. Before the test trials, subjects were instructed to fold their arms across their chest and give maximal effort. Subjects did five isokinetic concentric knee flexion and extension repetitions at 60°/second of their dominant limb.

RESULTS

All data were analyzed with a one-way analysis of variance (ANOVA) and the significance level was set at 0.05 a priori. For the single-leg landing task (Table 1), females revealed significantly greater hip internal rotation (F = 16.0; p = 0.000), less knee flexion (F = 10.6; p = 0.003), and less lower leg internal rotation (F = 11.4; p = 0.002) maximum angular displacement compared with the male subjects. The females also had significantly less time to maximum angular displacement of knee flexion (F = 6.9; p = 0.014) and lower leg internal rotation (F = 7.3; p = 0.012).

For the forward hop landing task (Table 1), the females had significantly less knee flexion (F = 6.8; p = 0.014) and lower leg internal rotation (F = 0.1; p = 0.005) maximum angular displacement compared with the male subjects. The females had significantly more time to maximum angular displacement for hip internal rotation (F = 17.5; p = 0.000) and significantly less time to maximum angular displacement for knee flexion (F = 4.7; p = 0.038) compared with the male subjects.

There were no significant differences found between groups for the vertical ground reaction force variables for either single-leg landing (females, 32.2 ± 5.4; males, 30.4 ± 5.5; F = 0.75; p = 0.39) or for the forward hop landing tasks (females, 28.8 ± 5.1; males, 28.4 ± 5.5; F = 0.04; p = 0.84).

For the isokinetic strength assessment (Table 2), females had significantly lower peak torque to body weight for knee extension (F = 7.55; p = 0.011) and flexion (F = 4.52; p = 0.043).

DISCUSSION

For both landing tasks, the results of the current study indicate that females have significantly less knee flexion and lower leg internal

TABLE 1. Landing Tasks Kinematic Data

Kinematic Variables	Hip Flexion	Hip Abduction	Hip Rotation	Knee Flexion	Lower Leg Rotation
Single-leg land					
Maximum angular displacement (degrees)					
Females	7.12 ± 5.57	−10.67 ± 8.85	7.49 ± 3.69*	−17.41 ± 12.96*	3.81 ± 3.42*
Males	6.65 ± 4.91	−6.09 ± 3.53	3.08 ± 2.16	−31.10 ± 9.92	11.73 ± 8.39
Time to maximum angular displacement (ms)					
Females	126.04 ± 57.39	136.24 ± 52.82	150.17 ± 52.62	130.04 ± 71.8*	174.32 ± 41.71*
Males	140.62 ± 62.86	147.84 ± 37.79	110.21 ± 66.65	187.00 ± 43.98	111.64 ± 33.54
Forward hop maximum angular displacement (degrees)					
Females	4.75 ± 3.3	−9.79 ± 8.41	4.96 ± 3.21	−18.95 ± 13.82*	4.23 ± 3.77*
Males	5.43 ± 5.79	−8.21 ± 3.7	3.09 ± 2.27	−30.35 ± 9.73	11.86 ± 9.04
Time to maximum angular displacement (ms)					
Females	102.22 ± 51.45	137.13 ± 43.91	124.05 ± 40.57*	130.49 ± 70.37*	84.85 ± 42.19
Males	95 ± 68.54	155.62 ± 39.23	64.15 ± 37.83	178.73 ± 49.42	99.27 ± 40.29

*Denotes statistical significance at $p < 0.05$

TABLE 2. Isokinetic Assessment: Peak Torque to Body Weight (N-m) at 60°/Second

Group	Quadriceps	Hamstrings
Females	222.93 ± 30.86*	113.74 ± 23.66*
Males	271.68 ± 59.27	131.72 ± 21.89

*Denotes statistical significance at $p < 0.05$

rotation after impact than males. The results also revealed that females took significantly less time to reach maximum knee flexion subsequent to impact. Because females had less maximum angular displacement than males, it did not take as long to reach their maximum knee flexion angle resulting in a more abrupt absorption of the impact forces of landing (Figs 3,4).

The kinematic pattern of the females in relation to the males during these landing tasks included more hip internal rotation with lower leg external rotation from impact to the maximum rotation point of the maneuver with knee flexion relatively limited. The kinematics during landing of the females in the current study were consistent with those often observed in the noncontact anterior cruciate ligament injury.[3,16] The relative lack of knee flexion, combined with a tibial rotary force, muscle reflex, or a combination of both in response to an unexpected perturbation may result in injury to the anterior cruciate ligament.[4,9,14,28,30,32,34]

The current results are consistent with results from other studies which showed there were gender differences when doing athletic maneuvers, such as cutting[4,19] and landing from a jump.[13] These studies showed that females tend to land with the knee in a more extended position[4,19] and therefore subject themselves to higher forces per body weight during the impact of landing.[13] Some reports attribute landing characteristics to training experience of the athlete.[2,8,21,24,27,31] In general, skilled, well-trained, or experienced athletes have been reported to have increased ankle plantar flexion,[21,24] knee flexion,[8,24,31] and lowered vertical ground reaction forces during landing.[27,31] Thus this theoretically would permit more time to distribute the impact forces and allow the opportunity for the musculature to absorb these forces.[24,31] However, to date, no studies have investigated a potential relationship of gender by skill level for these landing characteristics.

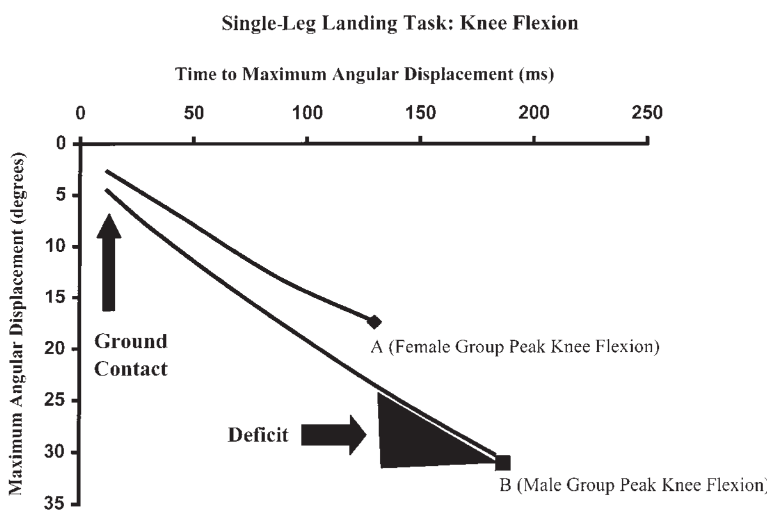

Fig 3. Points A and B represent the maximum angular displacement of knee flexion and the time to achieve this position after ground contact. The deficit represents a significant ($p < 0.05$) difference in knee position after ground contact between females and males.

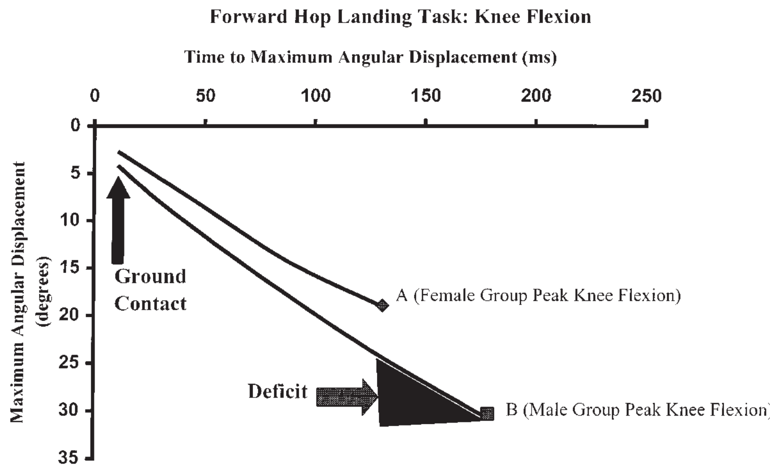

Fig 4. Points A and B represent the maximum angular displacement of knee flexion and the time to achieve this position after ground contact. The deficit represents a significant ($p < 0.05$) difference in knee position after ground contact between females and males.

The other significant result of the current study is related to the relative weakness of the female quadriceps and hamstrings when normalized to body mass compared with the males (Fig 5). This finding may play a fundamental role in the landing position observed in the females during landing.

The role of the quadriceps landing seems to be critical to the distribution and absorption of the impact forces resulting from landing. Although the vertical ground reaction forces did not differ between genders in the current study, the relative lack of knee flexion subsequent to impact in females has significant implications

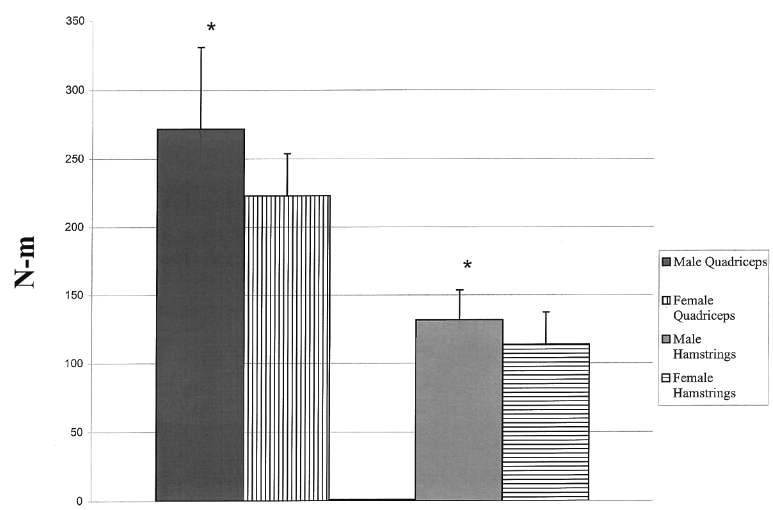

Fig 5. The quadriceps isokinetic peak torque to body mass at 60°/second for the male group was significantly greater ($p < 0.05$) than that of the female group. The hamstring isokinetic peak torque to body mass at 60°/second for the male group was significantly greater ($p < 0.05$) than that of the female group.

for the manner in which force transmission up the kinetic chain occurs. The authors suspect that the lack of vertical ground reaction force difference was attributed to other force absorbing compensatory mechanisms that were not studied, such as ankle kinematics or muscle activity.

Subsequent to impact, the quadriceps muscle eccentrically contracts to control knee flexion and decelerate the land. The minimal knee flexion at impact observed and the lack of controlled knee flexion deceleration in the female athletes may be related to the relatively weak leg musculature, especially the quadriceps. Without sufficient strength available to decelerate the body by the eccentric quadriceps mechanism, it seems that the females land in a more extended knee position and tend to maintain this extended position subsequent to ground contact rather than absorbing the impact with controlled knee flexion. This knee extended position, combined with internal hip rotation, makes females vulnerable for anterior cruciate ligament loading.

Physicians, athletic trainers, and others who are concerned with the care of athletes, need to evaluate the biomechanics of the female athletes to ensure proper technique is being used during landing activities and continue to educate coaches to implement training practices using proper techniques. Maximizing joint angles, specifically knee flexion, subsequent to impact will aid in attenuating potentially harmful forces and ensure protective biomechanical patterns, which may promote more appropriate muscle firing patterns to protect the knee. Additionally, awkward or poor landing skills may identify a specific muscle weakness. Additional research is needed to explore if a relationship exists between the weakness of muscles and poor landing tasks as center of gravity and trunk angle differences may alter hip and knee stability.

The data from this study suggest that biomechanical and neuromuscular variables differ between genders during impact on landing. Males had a greater amount of knee flexion subsequent to impact. The larger flexion displacement serves to attenuate impact forces reducing loads imposed on the joint. The absence of this controlled knee flexion in females may be related to the weaker quadriceps and hamstrings, resulting in an abrupt stiffening of the knee. These factors need to be considered related to the pathoetiology of anterior cruciate ligament injuries in the female athlete.

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