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Hip Abductor Function and Lower Extremity Landing Kinematics: Sex Differences

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Context: Rapid deceleration during sporting activities, such as landing from a jump, has been identified as a common mechanism of acute knee injury. Research into the role of potential sex differences in hip abductor function with lower extremity kinematics when landing from a jump is limited.

Objective: To evaluate sex differences in hip abductor function in relation to lower extremity landing kinematics.

Design: 2 × 2 mixed-model factorial design using a between-subjects factor (sex) and a repeated factor (test).

Setting: University laboratory.

Patients or Other Participants: A sample of convenience consisting of 30 healthy adults (15 women, 15 men) with no history of lower extremity surgery and no lower extremity injuries within 6 months of testing.

Intervention(s): Landing kinematics were assessed as subjects performed 3 pre-exercise landing trials that required them to hop from 2 legs and land on a single leg. Isometric peak torque (PT) of the hip abductors was measured, followed by an endurance test during which subjects maintained 50% of their PT to the limits of endurance. After a 15-minute rest period, subjects completed a 30-second bout of isometric hip abduction, from which we calculated the percentage of endurance capacity (%E). Immediately after exercise, subjects completed 3 postexercise landing trials.

Main Outcome Measure(s): PT, %E, and peak joint displacement (PJD) of the hip and knee in all 3 planes of motion.

Results: Women demonstrated lower PT values (5.8 ± 1.2% normalized to body weight and height) than did their male counterparts (7.2 ± 1.5% normalized to body weight and height, $P = .009$). However, no sex differences were seen in %E. Women also demonstrated larger knee valgus PJD (7.26° ± 6.61°) than did men (3.29° ± 3.54°, $P = .04$). Women's PT was moderately correlated with hip flexion, adduction, and knee valgus PJD; however, PT did not significantly correlate with men's landing kinematics. Regardless of sex, hip flexion ($P = .002$) and hip adduction ($P = .001$) were significantly increased following the 30-second bout of exercise.

Conclusions: Women demonstrated lower hip abductor PT and increased knee valgus PJD when landing from a jump, potentially increasing the risk of acute knee injury. Furthermore, correlations between hip abductor strength and landing kinematics were generally larger for women than for men, suggesting that hip abductor strength may play a more important role in neuromuscular control of the knee for women.

Key Words: biomechanics, knee, torque, motion analysis

Key Points

- Women demonstrated lower hip abductor peak torque than men.
- Hip abduction peak torque correlated moderately with hip flexion peak joint displacement in women.
- Hip flexion and adduction peak joint displacement increased after hip abduction isometric exercises.

Roughly 80% of all injuries to the anterior cruciate ligament (ACL) have been reported to be the result of noncontact mechanisms.[1,2] The most common mechanisms of noncontact ACL injuries in female volleyball, basketball, and soccer athletes have been proposed to involve rapid deceleration of the lower extremity, such as landing from a jump.[2,3] During this activity, the knee may be placed in an at-risk position described by Ireland[4] as the "point of no return." This position involves increased hip adduction and internal rotation with an associated increase in knee valgus and tibial external rotation.[4] Increased motions of the knee in these planes also have been suggested to increase strain on the ACL.[5,6]

Recently, Ford et al[7] and Kernozek et al[8] reported that women demonstrated significantly increased frontal-plane motion of the knee when landing compared with men. Increased frontal-plane motion may be secondary to inferior hip abductor function. Similar to the point of no return described for acute knee injury, increased knee valgus and tibial external rotation have been identified as potential mechanisms of chronic knee conditions including patellofemoral pain syndrome[9] and iliotibial tract friction syndrome.[10] In 2 studies involving these chronic conditions in runners, injured subjects demonstrated decreased hip abductor strength.[9,10] Subjects with poor hip abductor strength may demonstrate decreased proximal control of the hip, which then may result in inferior knee kinematics.

The relationship between hip abductor strength and chronic knee injury during prolonged activities suggests that the endurance of this muscle group also may play a vital role in neuromuscular control of the knee. Lower extremity fatigue protocols have resulted in altered force production,[11] proprioception,[12] coordination,[13] and landing kinematics.[14] Dirx et al[15] reported an increased injury incidence for handball players in the second half of play with increasing player fatigue and intensity of the game. In the latter portions of an athletic event, each athlete's level of fatigue depends on both the physical requirements of the playing position and individual endurance. Unfortunately, although the effects of fatigue have been evaluated frequently in the literature, no existing models assess between-subjects differences in endurance. Therefore, the purposes of our study were (1) to assess sex differences in hip abductor strength and endurance and the relationship with knee joint kinematics during protocols that mimic noncontact mechanisms of ACL injury and (2) to develop a model for testing between-subjects differences in hip abductor endurance.

METHODS

Design and Setting

A 2 × 2 mixed-model factorial design was employed for testing, with a between-subjects factor (sex) and a repeated factor (test). All testing procedures were approved by the institutional review board, and all subjects provided informed consent. Testing was performed at the Musculoskeletal Laboratory.

Subjects

Participants included a sample of convenience consisting of 30 healthy adults (15 women, 15 men) who volunteered for participation and provided informed consent. Height and mass were significantly larger for the men (age = 24.4 ± 3.0 years, height = 180.3 ± 1.4 cm, mass = 78.8 ± 14.1 kg) than for the women (age = 23.2 ± 2.9 years, height = 165.9 ± 6.7 cm, mass = 66.5 ± 7.3 kg). The following exclusions prevented a subject from participation: a history of orthopaedic pelvic, hip, knee, or ankle surgery; a history of significant injury to the hips or lower extremities within 6 months of testing; or not volunteering or choosing not to consent.

Instrumentation

Three-dimensional joint kinematics of the hip and knee were measured using Ascension's Flock of Birds electromagnetic sensors and Motion Monitor software (Innovative Sports Training Inc, Chicago, IL). Electromagnetic sensors were placed on the sacrum, the distal lateral thigh, and the proximal lateral shank using a combination of double-sided tape and Cover-Roll (Beiersdorf-Jobst, Charlotte, NC). Cardan angles were calculated using the definitions of joint coordinate systems recommended by the International Society of Biomechanics.[16] Before dynamic testing, we estimated the hip joint center using the functional approach described by Leardini et al,[17] with data being collected as subjects moved the hip into a minimum of 6 different static positions, representing positive and negative rotations about all 3 axes. Kinematic data were collected at a sampling rate of 100 Hz. In order to calculate peak joint displacement, we placed foot switches in the subjects' shoes to determine the time of ground contact. Footswitch data were collected at 1000 Hz and were synchronized with the kinematic data (Datapac [version 3.08; Run Technologies, Mission Viejo, CA] and Motion Monitor software. Excellent reliability of all kinematic variables was demonstrated during pilot testing, with intraclass correlation coefficients ($ICC_{2,1}$) ranging from .84 to .98.

Strength was quantified by measuring isometric peak torque (PT) with the Primus dynamometer (Baltimore Therapeutic Equipment, Baltimore, MD). The dynamometer also was used to quantify force production during the endurance test and the 30-second bout of isometric hip abduction. We have determined the accuracy of this dynamometer in measuring isometric torque of the hip abductors to be ±0.65 Nm (T.L.U., unpublished data, 2006). Also, we have previously demonstrated excellent intrasession reliability ($ICC_{2,1}$ = .99) using this system with this muscle group.[18] The dynamometer was calibrated weekly during testing.

Electromyographic (EMG) data were collected at 2000 Hz during endurance testing in order to ensure consistent subject effort. A 16-channel EMG system (model MPT-10007 transmitter and model MPRD-101 receiver; Run Technologies) recorded all muscle activity during testing. Subjects wore a battery-operated amplifier (Run Technologies) that collected muscle activity from the surface electrodes. A Myopac transmitter belt unit (Run Technologies) transmitted raw EMG signal via a fiberoptic cable to its receiver unit. The unit specifications include an amplifier gain of 2000, a common mode rejection ratio of 90 dB, and input impedance of 1 M. After reaching the receiver unit, the signal was processed through a 16-bit A/D board into a personal computer. The EMG raw data from the endurance test were stored and later were analyzed using Datapac software (Run Technologies).

Procedures

Before testing, we collected demographic information and subjects performed a submaximal 5-minute warm-up on a cycle ergometer. The preferred leg was defined as the landing leg that was used selectively at least 2 times when performing 3 uncontrolled practice trials of a double-leg hop with a single-leg landing. Testing consisted of the following components for the preferred landing limb: prefatigue functional landing trials (L_{pre}), strength testing, endurance testing, a submaximal 30-second bout of isometric exercise, and postfatigue landing trials (L_{post}) (Figure 1). During testing, all subjects wore the same low-top court shoe (Nike, Inc, Beaverton, OR).

Functional Testing

Each subject was asked to perform several repetitions of the functional landing task with the preferred landing leg. Subjects performed a 2-legged jump and landed on a single leg in a target area located on the floor (Figure 2). The target area was 25 cm wide and 50 cm long. The length and height of the jump were equivalent to 40% and 15% of the subjects' height, respectively. The length of the jump was controlled by moving the starting position the required distance away from the target area. In order to control the height of the jump, a soft foam target was suspended from the ceiling midway between the starting position and the target area. Subjects were asked to hit the foam block with the forehead during each trial. Upon landing, subjects were instructed to "stick" the landing, to stabilize quickly, and to remain as motionless as possible for up to 5 seconds. At least 3 practice trials were required, and subjects were allowed to perform as many practice trials as necessary until they were able to perform the landing task correctly. Three test trials of the landing task were performed before hip abductor strength and endurance testing (L_{pre}). After the submaximal 30-second bout of isometric exercise, 3

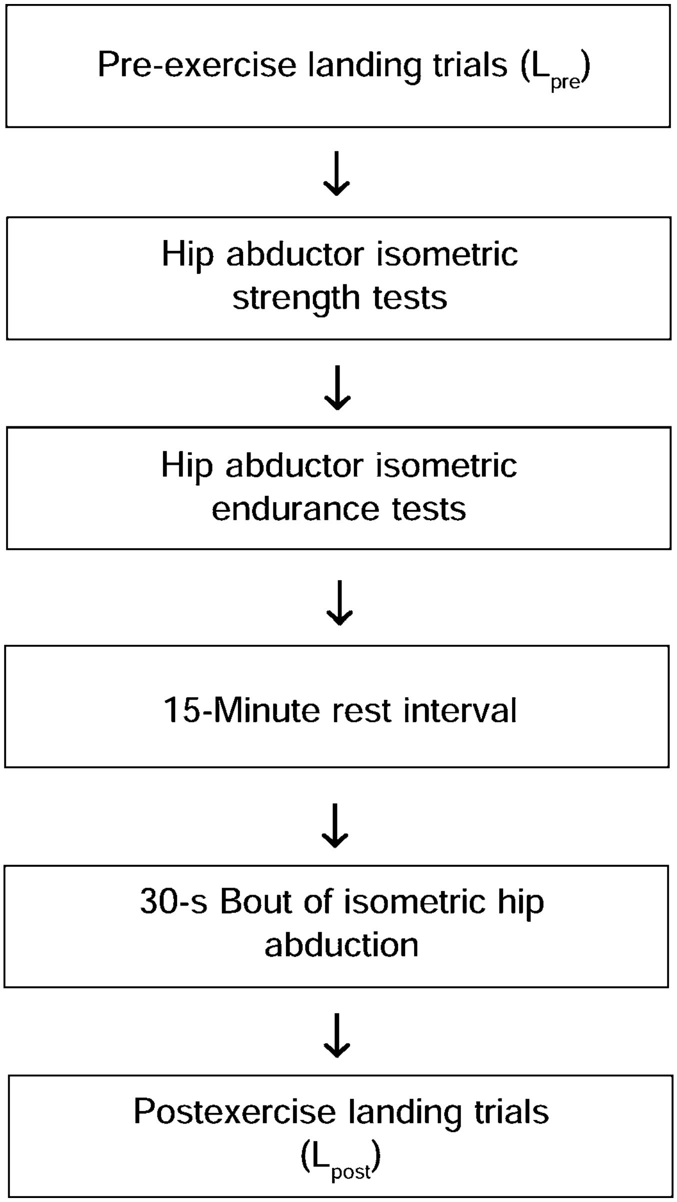

Figure 1. Data collection testing order.

additional test trials were performed (L_{post}). Initial joint angles were measured at the time of ground contact. Peak joint displacement was calculated as the difference between the joint angle at initial ground contact and the peak joint angle up to 500 milliseconds after contact. We selected this time value from previous time to peak joint angle data.[19] We found that the largest mean time to peak joint angle of the hip, knee, and ankle was 193.4 ± 67.2 milliseconds. For the current investigation, we selected 500 milliseconds as a conservative window for capturing the data, because this allowed for variations of more than 4 SDs above the mean. Previous authors[20] have used much larger time windows, in the range of 3 to 5 seconds. Time windows of this magnitude, however, may reflect peak joint angles experienced during stabilization instead of a direct result of the landing task itself.

Strength Testing

After performing the L_{pre} trials, subjects were asked to complete three 5-second maximal voluntary isometric contractions (MVICs) of the hip abductors. Thirty-second rest intervals were provided between maximal trials. Strength was quantified by measuring isometric PT with the dynamometer (Baltimore Therapeutic Equipment). Subjects were positioned lying on their sides with the hip neutrally aligned for testing (Figure 3).[18,21] The lever arm of the dynamometer was set so that the resistance pad was located just proximal to the lateral femoral epicondyle. Isometric PT measurements, recorded in Newton-meters, were obtained from each MVIC trial and then were normalized by body weight and height (%BWh), using the equation described by Fredericson et al.[10] Torque measures were normalized by both height and weight to account for the significant sex differences demonstrated by our sample population. Approximately 60 seconds after the strength test, subjects were asked to perform the endurance test.

Endurance Testing

Subjects were again tested in a side-lying, neutral position. Participants were required to maintain a submaximal (50% MVIC) contraction until muscular fatigue was achieved. Fatigue was defined as the point in time when the subject was no longer able to maintain the load for 3 consecutive seconds despite visual feedback and strong verbal encouragement.[22] Before the endurance test, subjects were given a 5- to 10-second practice trial to familiarize themselves with testing procedures and to experience the effort required to achieve the target load. During both the practice trial and endurance test, subjects viewed a line graph representing their force production on a monitor located directly in their line of sight. A dotted horizontal line represented the subject's target load (50% MVIC) and, as the test proceeded, a solid red line tracked across the screen and gave the subject real-time visual feedback of force production. Because force production was not constant throughout the endurance test, angular impulse values (torque × time) were recorded for each subject to account for slight fluctuations in effort. Subjects then were given 15 minutes' rest before performing the submaximal 30-second bout of isometric exercise in order to minimize the effects of fatigue. Fifteen minutes was selected as a conservative rest interval, ensuring that all subjects easily would exceed the 1:3 work-to-rest ratio previously suggested for repeated dynamic activities.[23]

In order to ensure consistent subject effort, EMG data were collected during the endurance test. Before testing, we shaved, abraded, and cleaned the skin with an alcohol preparation pad. Bipolar, 5-mm-diameter, Ag-AgCl surface electrodes (Ambu Inc, Linthicum, MD) were placed over the hip abductors with an interelectrode distance of 2.0 cm. The distance between the iliac crest and the greater trochanter was measured, and electrodes were placed one third of this distance distal to the iliac crest.[24] Electrodes were positioned parallel to the direction of the muscle fibers, and an additional ground electrode was placed over the acromion process. Previous authors have used this electrode placement specifically to target the gluteus medius muscle; however, we recognize that by testing the hip in neutral alignment, the muscle activity collected may include both the gluteus medius and minimus muscles. The purpose of collecting EMG data was to ensure fatigue during endurance testing; therefore, we performed analyses targeting the hip abductors as a group. The EMG data from the endurance test were arranged in 0.512-second time windows and were transformed using Datapac's (Run Technologies) Fast Fourier

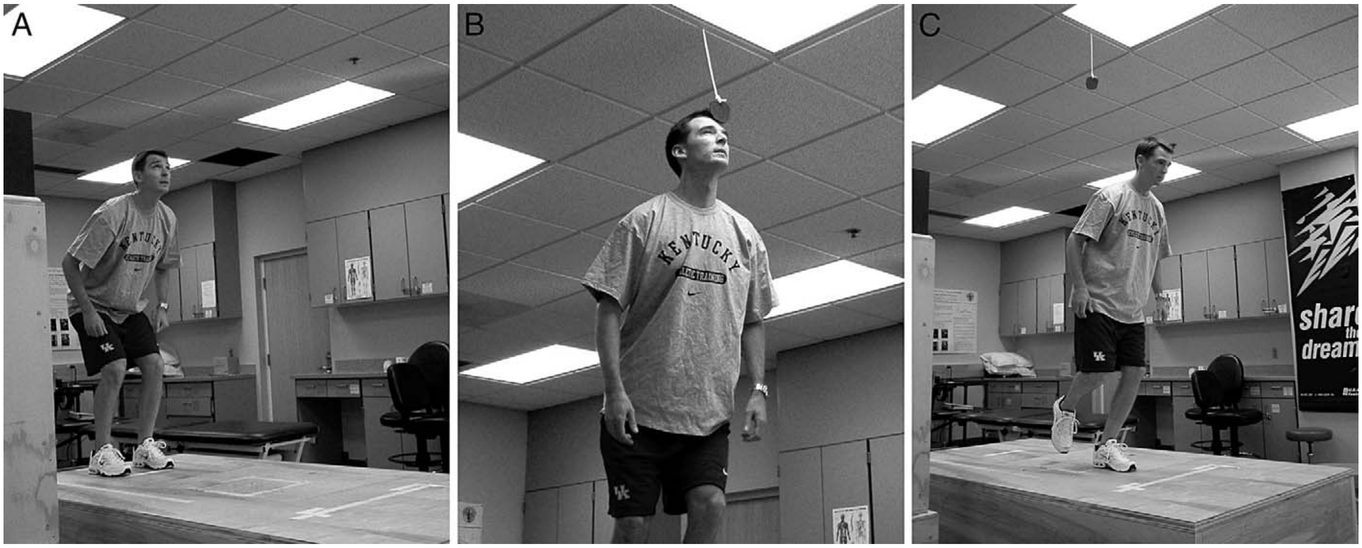

Figure 2. A demonstration of the functional landing task, which consists of the following: A, Double-leg hop. B, Hitting an overhead target. C, Landing on a single leg.

Figure 3. Subject position for hip abductor strength and endurance testing.

Transform method. The signal also was treated using the data demeaning and Hanning window functions available with the Datapac system. Median frequency (MF) values for each 0.512-second window were used to quantify the resulting power spectrum. The percentage change in MF (MF%) was calculated using the following equation: (average MF of last 5% of trial $-$ average MF of first 5% of trial) $\times$ 100.

The MF% was calculated and was recorded for each subject's preferred landing leg. The premise of this technique is that slow-twitch muscle fibers have low-frequency signals, whereas fast-twitch fibers have higher frequency signals. During fatiguing efforts, as fast-twitch fibers become fatigued and more emphasis is placed on slow-twitch fibers, a shift occurs from higher to lower frequency motor units.[25,26] The MF% values are generally negative, representing this shift. Greater MF% values indicate a larger shift and, therefore, the muscle demonstrates a reduced resistance to fatigue. In our investigation, subjects were excluded from analysis if they did not demonstrate an MF% value greater than 10%, because we would not be able to accurately report the percentage of maximal endurance during the 30-second bout of exercise if we could not ensure that the subject performed to the limits of endurance during maximal testing. However, all 30 subjects demonstrated MF% greater than 10%, with an average MF% of 18.1%.

Submaximal 30-Second Bout of Isometric Exercise

After the 15-minute rest interval, subjects were asked to perform a submaximal bout of isometric hip abduction in order to evaluate potential sex differences in hip abductor endurance. Subject positioning and load requirement (50% MVIC) were the same as for the endurance test. Unlike the endurance test, the submaximal bout of exercise was a consistent duration of 30 seconds for all subjects. During the bout, angular impulse values were recorded and were compared with the values obtained during the endurance test. This was performed to determine each subject's percentage of endurance capacity (%E) that was used for the submaximal 30-second bout of exercise. We defined %E as the angular impulse of the submaximal 30-second bout divided by the angular impulse of the full endurance test. A larger %E value indicated that the angular impulse of the 30-second bout was closer to that of the maximal endurance test. We hypothesized that because subjects with larger %E values would be closer to exerting a maximal effort, they would be more affected by the 30-second bout of exercise than those with lower %E values would be. With this in mind, we considered larger %E values to indicative of less endurance and, conversely, lower %E values indicative of increased endurance. Immediately after the 30-second exercise, subjects were asked to perform the 3 L_{post} trials. The mean time interval between the completion of the 30-second bout of exercise and initiation of the L_{post} trials was 17.5 seconds, which limited the amount of recovery of the hip abductors.

Statistical Analyses

Means and SDs were calculated for all dependent measures. Two-tailed, independent *t* tests were used to evaluate sex differences in PT and %E. Six separate 2 $\times$ 2 analyses of variance (group $\times$ time) were computed to compare PJD of the hip (flexion, adduction, and internal rotation) and knee (flexion, valgus, and external rotation) between women and men before and after an acute bout of isometric hip abduction. Separate Pearson product moment correlation coefficients were calculated to evaluate the relationship between hip abductor function and landing kinematics of men and women. Correlations with $P \leq .05$ were considered significant; however, a Bonferroni correction was used for the analyses of variance and *t* tests, yielding an adjusted α level of $P \leq .0063$. All calculations were performed using SPSS (version 12.0; SPSS Inc, Chicago, IL).

Table 1. Sex Differences in Hip and Knee Peak Joint Displacement During Jump Landing (Mean ± SD)

Joint Rotation	Men, °	Women, °	*P*	Cohen *d*
Hip flexion	26.11 ± 9.49	23.51 ± 8.73	.41	0.28
Hip adduction	10.33 ± 5.61	12.49 ± 6.93	.33	0.34
Hip internal rotation	13.36 ± 5.54	10.96 ± 6.89	.25	0.38
Knee flexion	42.04 ± 8.79	39.51 ± 8.88	.41	0.29
Knee valgus	3.29 ± 3.54	7.26 ± 6.61	.04	0.75
Knee external rotation	3.72 ± 2.67	3.85 ± 5.35	.93	0.03

Table 2. Pearson Product Moment Correlation Coefficients (*r*) Between Hip Abductor Normalized Peak Torque and Peak Lower Extremity Joint Displacements of Men and Women

	Hip			Knee		
Peak Torque	Flexion	Adduction	Internal Rotation	Flexion	Valgus	External Rotation
Women	−.58*	−.40	−.04	.12	−.35	−.11
Men	.34	.20	.10	.32	.09	.40
Overall	.06	−.16	.16	.28	−.30	.06

*Significant correlation ($P < .05$)

RESULTS

Women demonstrated lower PT values (5.8 ± 1.2% BWh) than did the men (7.2 ± 1.5% BWh, $P = .009$). The associated Cohen *d* value was 1.03, indicating a large effect size. No significant kinematic differences were seen between the sexes; however, the sex main effect for knee valgus PJD approached statistical significance ($F_{1,28} = 4.50$, $P = .04$) (Table 1). Women demonstrated knee valgus PJD of 7.26° ± 6.61° compared with 3.29° ± 3.54° in men. The associated Cohen *d* value was 0.75, indicating a moderate effect size. No sex main effects for the remaining kinematic variables or group-by-test interactions were seen. Women's PT correlated moderately with hip flexion, adduction, and knee valgus PJD, but PT did not correlate significantly with men's landing kinematics (Table 2).

No differences in endurance capacity were noted between men and women, with %E values of 57.0% ± 15.3% and 60.8% ± 20.0%, respectively. The %E data were normally distributed, ranging from 28.7% to 90.4%, with 20 of the 30 subjects demonstrating %E values within 1 SD of the overall mean. Significant test main effects indicated increased hip flexion ($F_{1,28} = 11.14$, $P = .002$) and adduction PJD ($F_{1,28} = 11.14$, $P = .001$) after the 30-second bout of exercise (Table 3). The %E correlated moderately with women's postexercise hip flexion PJD but not with other postexercise lower extremity landing kinematics of either sex (Table 4).

Table 3. Hip and Knee Peak Joint Displacement (Mean ± SD) Before (L_{pre}) and After (L_{post}) a 30-Second Bout of Isometric Hip Abduction

Displacement	L_{pre}, °	L_{post}, °	*P*	Cohen *d*
Hip flexion	22.82 ± 8.83	26.80 ± 9.15	.002	0.44
Hip adduction	10.17 ± 6.24	12.64 ± 6.31	.001	0.39
Hip internal rotation	11.53 ± 5.69	12.79 ± 6.92	.24	0.20
Knee flexion	40.61 ± 9.58	40.94 ± 8.23	.80	0.04
Knee valgus	5.19 ± 5.34	5.36 ± 5.99	.78	0.03
Knee external rotation	4.43 ± 4.52	3.14 ± 3.81	.02	0.33

Table 4. Pearson Product Moment Correlation Coefficients (*r*) Between Percentage of Endurance Capacity and Postexercise Peak Lower Extremity Joint Displacements of Men and Women

Percentage of Endurance Capacity	Hip			Knee		
	Flexion	Adduction	Internal Rotation	Flexion	Valgus	External Rotation
Women	.57*	.11	.18	−.08	−.22	.09
Men	−.15	.44	−.08	.27	−.38	.08
Overall	.21	.25	.05	.02	−.15	.00

*Significant correlation ($P < .05$).

DISCUSSION

The purpose of this study was to evaluate sex differences in hip abductor strength and endurance and lower extremity landing kinematics. Our discussion of results will focus individually on strength and endurance of the hip abductors and the role each muscular characteristic has in neuromuscular control of the lower extremity when landing from a jump, as well as the limitations and potential clinical implications of this study.

Hip Abductor Strength and Landing Kinematics

Hip abductor weakness has been associated previously with chronic knee injuries, including patellofemoral pain syndrome[9] and iliotibial tract friction syndrome.[10] These chronic conditions share mechanics of injury similar to those of acute ACL injury, including increased hip adduction and knee valgus displacement.[5,9,10] Recently, Ford et al[7] and Kernozek et al[8] used landing protocols to mimic a common mechanism of ACL injury. Both groups reported increased frontal-plane excursion of the knee when women landed from a jump. In a review of potential risk factors of ACL injury, Griffin et al[1] stated that neuromuscular control of the hip may influence the forces experienced by the knee. Given that women had weaker hip abductors and also demonstrated increased knee valgus PJD, our results support the neuromuscular link between the hip and knee, suggesting that the hip abductors assist in controlling knee motion during the dynamic activities associated with sport.

In the current investigation, women demonstrated nearly 4° more knee valgus displacement than men, resulting in a moderate effect size (Cohen $d = 0.75$). The clinical implications of these results are apparent when one considers the potential for increased strain on the ACL associated with an increase in knee valgus displacement of this magnitude. McLean et al[27] reported that women had peak knee valgus angles that were only 2° greater than those of men when performing a sidestep cutting maneuver. This change in knee valgus angle corresponded with an approximately 100% increase in valgus loads, making the knee more sensitive to valgus buckling.[27] Applying this to the current investigation, the 4° increase in knee valgus displacement could potentially result in a 200% increase in valgus loads for women.

Previous authors have suggested that the ability to land correctly depends less on muscular strength of the lower extremity and more on an individual's skill at landing.[28] However, our results suggest that subjects with increased hip abductor strength may have more beneficial knee landing kinematics. Two rationales may explain our results. First, subjects with increased PT of the hip abductors may demonstrate reduced knee valgus PJD as a result of enhanced proximal control of the hip. We did not measure strength of other lower extremity or core muscle groups, so we cannot be sure if the improved knee kinematics demonstrated by men were because the hip abductors were providing enhanced proximal control of the hip or because subjects with increased PT of the hip abductors were able to better use the quadriceps and hamstrings. Bobbert and van Zandwijk[29] reported that the ability of the quadriceps and hamstrings to resist forces experienced by the lower extremity when jumping is significantly improved with increased hip muscle activity. By either improving pelvic alignment or enhancing function of the quadriceps and hamstrings, increasing strength of the hip abductors may improve neuromuscular control of the knee when landing from a jump.

The overall correlation, regardless of sex, between hip abductor strength and knee valgus PJD in our investigation was very similar to that in other published reports. Independent of sex, Willson et al[21] reported a small correlation ($r = .23$) between hip abductor PT and the 2-dimensional knee frontal-plane projection angle as subjects performed a single-leg squat. Our correlation, regardless of sex, was −.31 between hip abductor PT and knee valgus PJD. The negative sign of the correlation between the 2 protocols can be explained by the fact that the direction of valgus displacement was a positive value in the current investigation, whereas the corresponding change in frontal-plane projection angle was a negative value in the protocol by Willson et al.[21] Assuming that the sexes do not differ in hip abductor utilization, the results of the 2 studies agree that a weak overall relationship exists between hip abductor strength and frontal-plane motion of the knee.

However, sex-specific correlations between hip abductor strength and lower extremity kinematics bring to light potentially different neuromuscular strategies between men and women. Men demonstrated generally small, positive correlations between strength and kinematics, whereas women demonstrated larger, negative correlations. Small, positive correlations suggest that the hip abductors do not play a significant role in controlling knee motion when men land from a jump. This finding is supported by the results of Stanley et al,[30] who measured preseason isokinetic hip abductor torque in male collegiate football athletes and the incidence of lower extremity noncontact injuries during the competitive season. The authors reported no differences in hip abductor strength between injured and uninjured male athletes, further suggesting that in men, this muscle group may not play a protective role in neuromuscular control of the lower extremity.

On the contrary, larger, negative correlations suggest that, for women, increased hip abductor strength correlates with decreased knee valgus displacement when landing from a jump. Women in the current investigation demonstrated inferior hip abductor strength compared with men. In addition, sex differences in bony structure and neuromuscular patterns potentially explain the increased role of the hip abductors during dynamic activities. It has been previously suggested that women have increased pelvic width-to-femoral length ratios.[21,31] Greater pelvic width-to-femoral length ratios result in the hips being generally in a more adducted position, which has been reported to increase both static and dynamic knee valgus angles.[32] Also, greater pelvic width increases the lever arm of the hip abductors, thus reducing the force production capabilities of this muscle group. Still, despite having weaker hip abductors that may be in a mechanically disadvantaged position, women could compensate for the reduced force production capabilities by increasing the activation of this muscle group. However, it appears that women do not demonstrate compensatory increases in hip abductor activation when landing from a jump. Recently, Russell et al[33] reported that men and women did not differ in gluteus medius activation during drop jumps, thereby suggesting that the gluteus medius activation could not explain the increased knee valgus angles demonstrated by women. It is our contention that a combination of these factors may exaggerate hip abductor weakness in women, thus making this muscle group a necessary target for preventive and rehabilitative strengthening programs.

Hip Abductor Endurance and Landing Kinematics

Muscles in a fatigued state may behave like weak muscles as they experience a reduced ability to produce force.[26] Reduction in force production, either from weak or fatigued muscles, limits the body's ability to attenuate the high forces associated with dynamic movements. Using a 2-dimensional analysis, Carcia et al[14] reported that when the hip abductors were fatigued, subjects landed in greater tibiofemoral valgus. The purpose of our study was not to evaluate knee kinematics when the hip abductors were fatigued but to compare kinematics in subjects with various levels of hip abductor endurance. The process of determining each subject's endurance capacity and then calculating the percentage of that capacity used during a 30-second bout of exercise is a novel approach to evaluate endurance of a muscle group. We developed this method in order to have a way of differentiating among subjects based on endurance, instead of fatiguing all subjects to the same level. Also, to improve the accuracy of this technique, we required at least a 10% reduction in EMG MF to ensure that peripheral changes were occurring during the endurance test and that our measure of endurance capacity was less limited by factors associated with central fatigue.

Landing kinematics were altered after a submaximal bout of isometric hip abduction. Regardless of %E, subjects demonstrated increased hip flexion and adduction after the 30-second bout of isometric hip abduction. Excessive hip flexion displacement may move the center of gravity forward, resulting in altered neuromuscular control of the knee. Female athletes trained by Hewett et al[34] were able to reduce noncontact ACL injuries by maintaining neutral alignment of the center of gravity with the chest above the knees, no excessive side-to-side or forward-backward motion, and a toe-to-heel landing strategy. This type of landing strategy would not be possible if the subject went through an increased range of hip flexion. The center of gravity would be too anterior, potentially resulting in knee hyperextension in an attempt to rock to the heel, thereby increasing the risk for acute knee injury.

LIMITATIONS

Our study design and methods had several limitations. The sex comparison we conducted was not the original intention of this protocol. As such, the power analysis performed to determine the sample size was based on pilot data no longer applicable to the current investigation; therefore, the sample size used in the study was not justified a priori. Our results can be generalized only to a population of healthy, college-aged subjects. We did not determined if subjects had prior participation in a jump or landing training protocol, which could have affected the current results. Also, we did not measure injury incidence, so we cannot speculate if strength or endurance of the hip abductors is associated with an increased incidence of ACL injury. Future investigators should apply the current techniques to investigate the role of the hip abductors on the landing kinematics of athletes, as well as the relationship to ACL injury.

In addition, strength and endurance of the hip external rotators were not assessed. Willson et al[21] recently suggested that strength of the hip external rotators was related to frontal-plane motion of the knee when performing a single-leg squat. Furthermore, Leetun et al[35] reported that strength of the hip external rotators was a predictor of lower extremity injury in collegiate athletes. Future research is necessary to determine if PT during a combined hip abduction-external rotation test described by Nyland et al[36] may solidify further the link between neuromuscular control of the hip with knee kinematics during dynamic activity. Also, without measuring pelvic alignment, we were unable to determine if increased hip abductor PT directly improved proximal control of the hip, or if neutral pelvic alignment during dynamic activity resulted in reduced knee valgus displacement.

The duration of the acute exercise bout may not have been long enough to elicit dramatically altered hip abductor function. It is important to remember that our purpose was not to assess kinematic changes after fatigue of the hip abductors but to evaluate if subjects with greater hip abductor endurance demonstrated more beneficial kinematics during a landing task after a submaximal bout of exercise. However, we have a limited ability to make conclusions about the role of hip abductor endurance during landing, because the %E values of the 2 groups were not significantly different. Also, we did not stringently control subject position during isometric testing, so subjects may have been able to compensate with other muscle groups. Furthermore, the normal distribution of %E data in our sample of 30 healthy subjects inherently limits the magnitude of correlations one could expect. Future authors may improve upon our methods by either increasing the duration of the bout of exercise or including repeated bouts of exercise.

CONCLUSIONS

Women demonstrated lower hip abductor PT and increased knee valgus PJD when landing from a jump. Furthermore, correlations between hip abductor strength and landing kinematics were generally larger for women than men. Sex differences in neuromuscular control of the knee may increase the importance of hip abductor function for women, thus making this muscle group a necessary target for preventive and rehabilitative strengthening programs.

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