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ORIGINAL RESEARCH

THE INFLUENCE OF HIP STRENGTH ON KNEE KINEMATICS DURING A SINGLE-LEGGED MEDIAL DROP LANDING AMONG COMPETITIVE COLLEGIATE BASKETBALL PLAYERS

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ABSTRACT

Background: A smaller knee flexion angle and larger knee valgus angle during weight-bearing activities have been identified as risk factors for non-contact anterior cruciate ligament (ACL) injuries. To prevent such injuries, attention has been focused on the role of hip strength in knee motion control. However, gender differences in the relationship between hip strength and knee kinematics during weight-bearing activities in the frontal plane have not been evaluated.

Hypothesis/Purpose: The purpose of this study was to determine the influence of hip strength on knee kinematics in both genders during a single-legged landing task in the frontal plane. The hypotheses were that 1) subjects with a greater hip strength would demonstrate larger knee flexion and smaller knee valgus and internal rotation angles and 2) no gender differences would exist during the single-legged landing task.

Methods: Forty-three Japanese collegiate basketball players (20 males, 23 females) participated in this study. Three-dimensional motion analysis was used to evaluate knee kinematics during a single-legged medial drop landing (SML). A hand-held dynamometer was used to assess hip extensor (HEXT), abductor (HAB), and external rotator (in two positions: seated position [SHER] and prone [PHER]) isometric strength. Spearman rank correlation coefficients (ρ) were determined for correlations between hip strength and knee kinematics at initial contact (IC) and peak (PK) during SML ($p < 0.05$).

Results: Negative correlations were observed between the knee valgus angle at IC and HEXT ($\rho = -0.48$, $p = 0.02$), HAB ($\rho = -0.46$, $p = 0.03$) and PHER ($\rho = -0.44$, $p = 0.04$) strength in females. In addition, a significant positive correlation was observed between the knee flexion angle at PK and HEXT strength ($\rho = 0.61$, $p = 0.004$) in males.

Conclusions: Significant correlations between hip strength and knee kinematics during SML were observed in both genders. Hip strength may, therefore, play an important role in knee motion control during sports activities, suggesting that increased hip strength may help to prevent non-contact ACL injuries in athletes of both genders. Moreover, gender-specific programs may be needed to control abnormal knee motion, as the influence of hip strength on knee kinematics may differ based on gender.

Level of Evidence: 3

Keywords: Gender differences, hip strength, knee biomechanics, risk of anterior cruciate ligament injury

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INTRODUCTION

Non-contact anterior cruciate ligament (ACL) injuries frequently occur in female athletes who participate in sports requiring deceleration and sudden changes of direction at a four- to six-fold greater injury rate than males participating in the same sports.[1-4] Following ACL injuries, many athletes choose ACL reconstruction surgeries, and they face other problems such as medical treatment expenses and academic performance issues.[3,5] Additionally, the rates of ACL reoperation (37.1%) and re-injury (11.9%) following ACL reconstruction are high in collegiate patients.[6,7] Therefore, emphasis has been placed on understanding the mechanism of ACL injury, using biomechanical analysis.

According to the authors of previous cross-sectional studies, females had a smaller knee flexion angle and larger knee valgus and internal rotation angles compared with males; therefore, these knee motions have been identified as risk factors for non-contact ACL injury.[8-10] Additionally, in a longitudinal study, female athletes who sustained non-contact ACL injuries during an athletic preseason demonstrated smaller knee flexion and larger knee abduction angles during a drop vertical jump maneuver compared to athletes who did not sustain ACL injuries.[11] Video analysis of knee motion during non-contact ACL injuries revealed a decrease in the knee flexion angle and increase in the knee abduction and internal rotation angles during the moment of injury.[12-14] Another study utilizing video analysis revealed there were gender differences in the mechanism of ACL injury in basketball players.[15] Krosshaug et al found that female athletes demonstrated more knee flexion angle (15°) than male athletes did (9°) at the moment of ACL injury.[15] Therefore, the control of abnormal knee motion based on gender may play an important role in reducing the risk of non-contact ACL injury.

Recently, the influence of hip strength on knee function has been a focus of ACL injury prevention. Leetun et al reported that female athletes who sustained ACL injuries during an athletic season demonstrated decreased hip abduction and external rotation strength compared with those who sustained other lower extremity injuries or did not sustain ACL injuries.[16] Furthermore, subjects with diminished hip abduction strength demonstrated larger positions of knee abduction during treadmill running compared with those with strong hip abductors.[17] In addition, hip extension and abduction strength and the peak knee flexion angle all increased significantly during a drop landing task following a four-week training course that emphasized the musculature of the hip.[18] The results of these studies indicate that hip strength may alter the lower extremity biomechanics associated with ACL injury risk.

However, the relationship between hip strength and knee kinematics during weight-bearing activities has remained controversial. Many researchers have employed the single leg squat task to assess knee kinematics and found that subjects with greater hip strength demonstrated less knee valgus motion or lower frontal plane projection angles at the knee.[19-22] Furthermore, McCurdy et al reported significant negative correlations between hip extension and abduction strength and knee valgus angle during a bilateral drop jump and with hip extension strength and knee valgus angle during a unilateral drop jump.[23] Therefore, hip strength may play an important role in the control of frontal plane knee motion.

In contrast, several authors have reported no significant correlations between hip strength and knee kinematics. For example, Jacobs et al observed a moderate but non-statistically significant negative correlation between hip abduction strength and knee valgus peak joint displacement during a single leg landing task.[24] Moreover, Thijs et al reported the lack of significant correlations between hip strength and knee kinematics during a lunging task.[25] Sigward et al found no significant correlations among hip extension, abduction and external rotation strength, and knee kinematics during a drop landing task.[26] Furthermore, Hollman et al reported that an increase in hip strength may be associated with an increase in knee valgus angle during a single-limb step down.[27]

Authors of previous studies have employed weight-bearing activities during sagittal plane activities (e.g., single leg squat, lunge, and drop jump) to assess knee kinematics. However, the sports in which non-contact ACL injuries occur frequently require multi-directional movement.[3,12] Therefore, the evaluation of knee kinematics during weight-bearing activities performed in the frontal plane is highly essential in determining the relationship between hip strength and knee kinematics. Additionally, single leg landing has been identified as a landing task associated with a risk of non-contact ACL injury.[12] Therefore, assessing the relationship between hip strength and knee kinematics during a single leg landing task in the frontal plane may help elucidate the influence of hip strength on the control of knee motion.

A few earlier studies have evaluated gender differences in the relationship between hip strength and knee kinematics.[22,24] However, no current studies have assessed the relationship between hip strength and knee kinematics during a single leg landing task in the frontal plane. Therefore, the purpose of this study was to determine the influence of hip strength on knee kinematics during a single-leg landing task in the frontal plane in athletes of both genders. The first hypothesis was that subjects with greater hip strength would demonstrate a larger knee flexion angle and smaller knee valgus and internal rotation angles. The second hypothesis was that no gender differences would be observed in this relationship during the single-leg landing task.

METHODS

Subjects

Sixty-eight Japanese competitive intercollegiate basketball players (32 males and 36 females) from three different local universities were recruited for this study. All subjects completed informed consent and medical history questionnaire forms. Based on the results of the medical health questionnaire forms, subjects were excluded if they met the following conditions: 1) a history of spinal or lower extremity surgery, 2) history of spinal or lower extremity injury within the past three months, and 3) neurological disorders affecting the lower extremities. A total of 43 eligible subjects (20 males: age = 20.20 ± 1.54 years, height = 176.87 ± 6.95 cm, body mass = 73.55 ± 7.98 kg; 23 females: age = 19.96 ± 0.77 years, height = 164.36 ± 8.42 cm, body mass = 58.31 ± 6.86 kg) participated in the study. All females were right limb dominant. There were two left limb dominant and 18 right limb dominant males. Knee kinematic and hip strength assessments were performed on the dominant leg only (i.e., preferred leg for strongly kicking a ball). The sample size for this study was based on a previous study, which determined relationship between knee valgus and hip muscle strength.[27] The study protocol was approved by the Institutional Review Board of Niigata University, Niigata University of Management, and Niigata Institute of Health and Sports Medicine.

PROCEDURES

Hip Strength Measurements

A handheld dynamometer (Power Track Commander II ™; JTECH Medical, Salt Lake City, UT, USA) was used to isometrically measure hip strength. This instrument is widely used to evaluate hip strength in clinical settings and has exhibited excellent intraclass correlation coefficients for measuring maximal voluntary isometric hip strength.[27,28] All hip strength measurements were obtained by a single examiner who has been a certified athletic trainer for 14 years and certified strength and conditioning specialist for 10 years.

For hip extension strength measurements, subjects were placed in the prone position on a table, with the knee flexed at 70°–90° (Figure 1a). Subjects were allowed to hold the side of the table with both hands during the testing session. The examiner placed the HHD 5 cm proximal to the knee joint line.[29]

Hip abduction strength was measured with the subject positioned side-lying on the table, with the hip and knee in a neutral position (Figure 1b). The hip and knee joints of the lower (non-tested) leg were flexed to 90°. The subjects were instructed to hold on to the side of the table with their upper hand and the top of the table with their lower hand during the testing session. The examiner applied the HHD 5 cm proximal to the lateral malleolus.[29]

Two different positions (SHEX and PHEX) were selected to measure the hip external rotation strength, as a previous study indicated that the hip angle changed the degree of hip external rotation torque. [30] For strength testing in the SHEX position, subjects were seated on the table with the hip and knee flexed at 90° (Figure 1c) and instructed to hold on to the side of the table during the testing session. The HHD was applied 5 cm proximal to the medial malleolus.[29] For the PHEX position, subjects were placed in the prone position with the hip in a neutral position and the knee flexed at 90° (Figure 1d) while

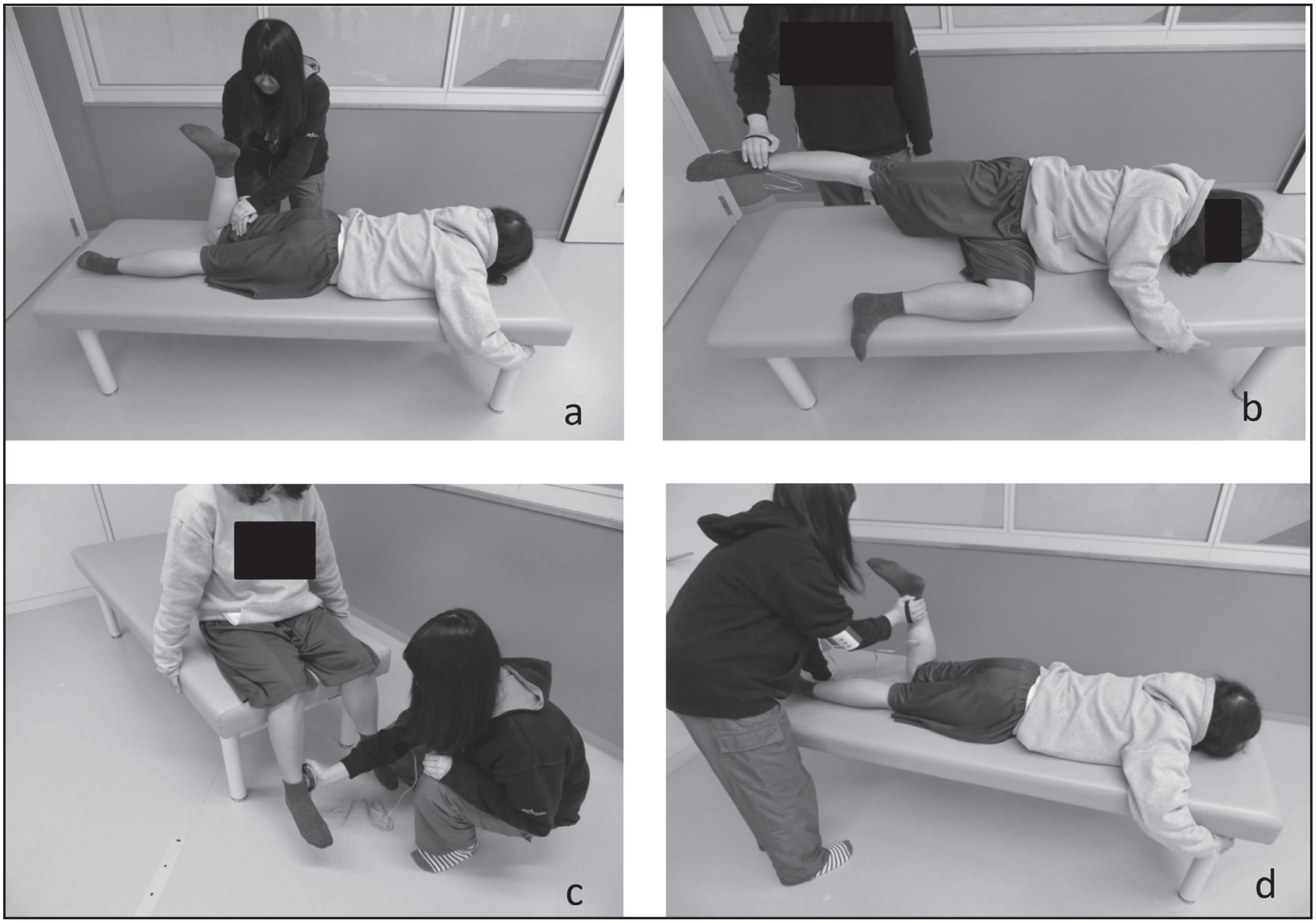

Figure 1. *Hip Strength. a: Hip Extension (HEXT), b: Hip Abduction (HAB), c: Hip External Rotation in the Seated Position (SHER), d: Hip External Rotation in the Prone Position (PHER).*

they held on to the side of the table with both hands. The examiner placed the HHD 5 cm proximal to the medial malleolus.[29]

All hip strength measurements were collected for the dominant leg. During the testing session, the subjects performed two sub-maximal trials to ensure the correct test position. After the sub-maximal trials, they performed two successful test trials (using a make-test). The average of the two test trial values was used to indicate hip strength. The duration of each trial was 5 seconds, separated by a 30 sec rest period. The order of muscle testing was randomized to reduce systematic bias. When compensatory motion was detected by the examiner, a retest was ordered after a 30 second rest period. All hip strength data were normalized to body weight according to the following formula: (kg strength/kg subject`s body mass) x 100 (%BW).[28]

Before the study began, a pilot study was conducted to confirm the test-retest reliability of the examiner who performed the strength testing during this study.[28] Eight healthy active undergraduate students who exercised at least two times per week for at least 30 minutes were recruited. The subjects were tested twice within one week, using the same protocol described above. The intra-class correlation coefficients ($ICC_{1,2}$) ranged from 0.93 to 0.99, indicating excellent reliability.

SINGLE-LEGGED MEDIAL DROP LANDING (SML)

Reflective markers were placed on the following anatomical locations: head (top, back, and side), manubrium, xiphoid process, spinous process of the seventh cervical vertebra and tenth thoracic vertebra, apex of the sacrum, bilaterally on the acromion processes, olecranon processes, styloid processes of the radius, anterior superior iliac spines, posterior superior iliac spines, greater trochanters, lateral and medial epicondyles of the knees, center of the patellae, tibial tuberosities, lateral aspects of the mid and distal shank, posterior aspects of the distal shank, lateral and medial malleoli, calcanei, second metatarsals, and fifth metatarsals. Once the markers were attached, a static trial was performed to determine each subject's neutral alignment. Marker placements were an original set determined by the authors, used for this study.

The SML, which was used to assess knee kinematics during a single leg landing task in the frontal plane, was conducted first.[31] The SML is performed by completing a single leg drop landing from a 20-cm box. Subjects were instructed to stand on their dominant leg on the box and then asked to drop-off the box medially onto the force plate using the same leg and hold the landing position for three seconds. Subjects were asked to perform six practice trials to familiarize themselves with the task. Once the subjects were comfortable with the task, they were asked to perform three successful trials.

All hip strength measurements and the SML test were performed at the Niigata Institute of Health and Sports Medicine on the same day. SML test was conducted prior to hip strength measurements. To minimize the fatigue effects, 10 minutes rest time was provided after SML measurements and before hip strength measurements.

DATA ANALYSIS

An eight infrared camera motion capture system (VICON T 10, Vicon Motion Systems, UK) and four 600 × 900 mm^2 force platforms (Kistler Co. Switzerland) were used for data collection. The sampling rates were 120 Hz and 240 Hz, respectively. All kinematics data were smoothed using a fourth-order zero-lag Butterworth filter with a cut-off frequency of 20 Hz.[32] Local coordinate systems of the head, trunk, pelvis, thigh, shank, and foot were determined based on the static standing position. The knee joint center was estimated from the center of the lateral and medial epicondyles of the femur. Vertical ground reaction force (vGRF) data were determined at the initial contact (IC) (vGRF > 10 N) during SML. The movement cycle was defined from the IC to the peak (PK), which was operationally defined as the moment at which maximum knee flexion angle was observed. The knee flexion (+)-extension (-), valgus (+)-varus (-), and internal rotation (+)-external rotation (-) angles at IC and the maximum angles observed from IC to PK were recorded for each trial. The knee kinematics for three SML trials were averaged and used in the statistical analysis.

STATISTICAL ANALYSES

Some variables were not normally distributed according to the Shapiro–Wilk test; therefore, the Mann–Whitney U test was used to determine gender differences in hip strength and knee kinematics during SML. Spearman rank correlation coefficients (ρ) were used to determine the correlations between hip strength and knee kinematics during SML. The significance level was set at $p < 0.05$. All data analysis was performed using SPSS (version 19.0; SPSS Inc., Chicago, IL, USA).

RESULTS

The variables for hip strength and knee kinematics are presented in Tables 1 and 2, respectively. Females had significantly weaker HAB (females: 18.48 ± 4.79 %BW vs. males: 21.65 ± 3.82 %BW, $p = 0.03$), SHER (females: 18.73 ± 3.75 %BW vs. males: 24.18 ± 3.90 %BW, $p < 0.01$), and PHER values (females: 19.51 ± 4.19 %BW vs. males: 25.51 ± 3.69 %BW, $p < 0.01$) when compared with males. (Table 1) Significant gender differences were also observed in knee kinematics during SML. Relative to males, females exhibited significantly greater knee flexion angles at IC (females: 26.94° ± 4.30 vs. males: 23.17 ± 4.29°, $p = 0.006$) and internal rotation angles at IC (females: −0.38 ± 6.12° vs. males: −6.01 ± 6.12°, $p = 0.02$) and PK (females: 2.05 ± 8.08° vs. males: −4.13 ± 4.97°, $p = 0.01$).

The Spearman rank correlation coefficients between the variables of interest are shown in Tables 3 and 4. In females, the knee valgus angle at IC exhibited significant negative correlations with hip extension (ρ = −0.48, $P = 0.02$), hip abduction (ρ = −0.46, $p = 0.03$), and the PHER value (ρ = −0.44, $p = 0.04$).

Table 1. *Gender Differences in Hip Strength. Expressed as Mean ± SD (95% Confidence Interval)*

Variables	Male, %Body weight	Female, %Body weight	*p*-value
HEXT	42.64±7.91 (38.93, 46.34)	39.35±8.13 (35.84, 42.87)	.21
HAB*	21.65±3.82 (19.86, 23.44)	18.48±4.79 (16.41, 20.55)	.03
SHER*	24.18±3.90 (22.36, 26.01)	18.73±3.75 (17.11, 20.35)	<.01
PHER*	25.51±3.69 (23.98, 27.43)	19.51±4.19 (17.70, 21.32)	<.01

*Significant gender differences: $p<.05$.

Abbreviations: HEXT, hip extension; HAB, hip abduction; SHER, hip external rotation with the seated position; PHER, hip external rotation with the prone position.

Table 2. *Gender Differences in Knee Kinematic During Single Legged Medial Drop Landing. Reported as mean ± SD (95% Confidence Interval)*

Knee Angle	Phase	Male (degrees)	Female (degrees)	*p*-value
Flexion(+)	Initial Contact*	23.17±4.29 (21.55, 25.46)	26.94±4.30 (25.06, 28.78)	.006
	Peak	62.40±8.51 (58.42, 66.39)	65.12±6.79 (62.18, 68.06)	.15
Valgus(+)	Initial Contact	4.86±4.49 (1.34, 5.71)	5.23±4.14 (1.71, 6.57)	.51
	Peak	13.20±7.24 (9.87, 17.85)	13.86±8.53 (10.07, 16.33)	.85
Internal Rotation(+)	Initial Contact*	−6.01±6.12 (−12.06, −7.07)	−0.38±6.12 (−7.07, −0.33)	.02
	Peak*	−4.13±4.97 (−6.46, −1.80)	2.05±8.08 (−1.44, 5.55)	.01

*Significant differences between genders: $p<.05$.

No other significant correlations were observed in females. In males, a significantly positive correlation was observed between the knee flexion angle at PK and hip extension (ρ = 0.61, p = 0.004). No other significant correlations were observed in male subjects.

DISCUSSION

Significant correlations were observed between hip strength and knee kinematics during SML in males and females, thus supporting first hypothesis. Knee valgus angle at IC during SML correlated negatively with HEXT, HAB, and PHER strength in females; in

Table 3. *Spearman Rank Correlation Coefficients (ρ) Between Hip Strength and Knee Kinematics in Females*

	Knee Anlge @ Initial Contact						Knee Angle @ Peak					
	Flx		Val		IR		Flx		Val		IR	
	ρ	*p*	ρ	*p*	ρ	*p*	ρ	*p*	ρ	*p*	ρ	*p*
HEXT	0.13	.57	−0.48	.02*	−0.20	.36	0.04	.85	−0.41	.05	−0.25	.26
HAB	0.22	.31	−0.46	.03*	−0.02	.94	0.17	.45	−0.39	.06	−0.81	.72
SHER	0.08	.72	−0.27	.21	−0.33	.13	−0.02	.91	−0.30	.17	−0.33	.12
PHER	0.05	.81	−0.44	.04*	−0.13	.56	−0.06	.79	−0.37	.08	−0.24	.27

*Significant gender differences: *P*<.05.

HEXT= hip extension; HAB= hip abduction; SHER= hip external rotation in the seated position; PHER= hip external rotation in the prone position; Flx= flexion; Val= valgus; IR= internal rotation.

Table 4. *Spearman Rank Correlation Coefficients (ρ) Between Hip Strength and Knee Kinematics in Males*

	Knee Anlge @ Initial Contact						Knee Angle @ Peak					
	Flx		Val		IR		Flx		Val		IR	
	ρ	*P*	ρ	*P*	ρ	*P*	ρ	*P*	ρ	*P*	ρ	*P*
HEXT	0.23	.33	0.23	.33	−0.17	. 48	0.61	.004*	0.31	.18	0.02	.93
HAB	−0.04	.86	−0.05	.83	−0.33	. 16	0.40	.08	0.07	.78	−0.26	.27
SHER	−0.15	.54	0.05	.82	−0.11	.65	0.36	.12	0.14	.57	0.01	.99
PHER	−0.05	.83	0.26	.26	−0.07	.65	0.08	.72	0.30	.21	−0.07	.77

*Significant gender differences: *P*<.05.

Abbreviations: HEXT, hip extension; HAB, hip abduction; SHER, hip external rotation with the seated position; PHER, hip external rotation with the prone position, Flx; flexion, Val; valgus, IR; internal rotation.

other words, females with greater HEXT, HAB, and PHER strength demonstrated a smaller knee valgus angle during SML. Several previous studies have reported similar results. McCurdy et al and Stickler et al observed a negative relationship between hip extension strength and the knee valgus angle during a unilateral drop landing and single leg squat in females.[22,23] Additionally, Baldon et al and Stickler et al reported a negative correlation between hip abduction strength and the knee valgus angle and concluded that increased hip abductor strength may play an important role in knee valgus angle control during a single leg squat in females.[21,22] Also, McCurdy found a negative correlation between hip abduction and knee valgus during bilateral landing in females.[23] Claiborne et al, Willson et al, and Stickler et al also reported that hip external rotation strength negatively correlated with the knee valgus angle during single leg squat, indicating that an increase in hip external rotation strength may contribute to a reduced knee valgus angle.[19-21] The results of the current study agree with those of previous studies, despite the use of a different task, the SML, to assess knee kinematics. Given that an increased knee valgus angle has been identified as a risk factor for non-contact ACL injuries,[8-11] HEXT, HAB and HER strength may therefore play an important role in reducing the knee valgus angle during weight-bearing activities in the frontal plane. Accordingly, an increase in hip strength may be worth investigating for the prevention of non-contact ACL injuries in females.

Another important finding of the current study was the positive correlation between HEXT strength and maximum knee flexion angle during SML in males, indicating that males with greater HEXT strength demonstrate larger knee flexion angles during SML. Previous authors found no significant relationship between hip strength and knee kinematics during single leg squat and single leg landing task in male subjects.[21,24] To the best of the authors' knowledge, the current study was the first to identify the relationship between hip strength and knee kinematics in males. The rationale why this result occurred may be based upon the gender differences for the mechanism of ACL injury. Compared with female athletes, male athletes demonstrated less knee flexion angle at the moment of ACL injuries.[15] Given that a smaller knee flexion angle has been identified as a risk factor for non-contact ACL injuries,[8-11] the results of this study suggest that even in males, HEXT strength may play an important role in ensuring a safer landing technique.

However, the influence of hip strength on knee kinematics during SML differed according to gender, which contradicted second hypothesis. Gender differences in the mechanism of non-contact ACL injuries may also explain this result. Based on a video analysis, male subjects demonstrated a smaller knee flexion angle at the moment of ACL injury, whereas females exhibited a larger knee valgus angle upon ACL injury.[15] Therefore, motions considered to increase the risk of non-contact ACL injuries may differ between the genders. Moreover, previous studies have revealed gender differences in the influence of hip muscles on lower extremity injuries. Leetun et al reported that female athletes who sustained ACL injuries during the athletic season exhibited weak hip abductor and external rotator strength during pre-season training.[16] In contrast, no association has been observed between hip abductor strength and lower extremity injuries in male football players.[33] These studies suggest that the influence of hip strength on knee injuries may differ according to gender. The present study observed correlations between knee valgus angle and hip strength in females and between knee flexion angle and HEXT in males. Therefore, gender-based differences in the influence of hip muscles on the mechanism of noncontact ACL injuries may have influenced knee kinematics during SML, suggesting that gender-specific exercise programs may be needed to correct abnormal knee motion during sports activities.

The relationship between hip strength and knee kinematics remains controversial.[19-27] Some previous authors did not find significant correlations between hip strength and knee kinematics or adverse effects on knee kinematics.[25-27] In addition, no previous authors have found a significant correlation between hip strength and knee kinematics in male subjects during weight-bearing activities.[21,24] However, the results of the present study demonstrated significant correlations between hip strength and knee kinematics during SML in both genders. Admittedly, the selected task used for analysis of movement may have affected the results of this study. Most studies that observed correlations between hip strength and knee kinematics employed a single leg landing task in the sagittal plane when evaluating knee kinematics.[19-22] However, during sports activities, athletes are required to control knee motion from multi-directional forces. In the video analysis, athletes who injured ACL show not only forward but also medial movements during a single landing.[12] SML comprises a single leg landing task in the frontal plane, which may be more similar to the sports specific task than a bilateral landing task or single leg landing task in the sagittal plane. As a result, there were significant correlations between hip strength and knee kinematics in both genders in this study. As multi-directional motion is required during sports activities, addressing deficits in hip strength may help to correct abnormal knee motion during weight-bearing activities and thus prevent non-contact ACL injuries in athletes of both genders.

This study has several limitations. The first limitation is that voluntary isometric contractions (VIC) were utilized to assess hip strength using a HHD. This method was chosen because it has been widely used to measure hip strength,[20,25-27] and is reported to be highly reliable.[28,34] However, the types of hip muscle contractions vary greatly during SML and include both concentric and eccentric muscle contractions. In future studies, other muscle contraction patterns or types should be addressed to clarify the relationship between hip strength and knee kinematics. The second limitation concerns the instrumentation used to assess hip strength in this study: specifically, a HHD without external fixation. Several other previous authors have used an isokinetic dynamometer to assess hip strength, and hip extension strength in females was significantly weaker than that in males.[19,24] However, the results of the present study did not demonstrate a significant gender difference in hip extension strength. A recent study concluded that external fixation may eliminate the influence of tester strength;[35] therefore, measuring hip strength using a HHD with an external fixation or an isokinetic dynamometer may facilitate more accurate hip strength assessments.

CONCLUSION

The results of the present study indicate that female collegiate basketball players with greater hip extension, abduction, and external rotation strength demonstrated less knee valgus angles during SML. Furthermore, male basketball players with greater hip extension strength demonstrated increased knee flexion angles during SML. Therefore, an increase in hip strength may play an important role in reducing abnormal knee motion in both female and male collegiate basketball players during weight-bearing activities in the frontal plane, which may help correct abnormal knee motion during sports activities. However, the influence of hip strength on knee kinematics differed according to gender. Therefore, gender-specific consideration may be needed for the non-contact ACL injury programs.

REFERENCES

1. Agel J, Arendt EA, Bershadsky B. Anterior cruciate ligament injury in national collegiate athletic association basketball and soccer: a 13-year review. *Am J Sports Med.* 2005;33(4):524-530.
2. Ireland ML. Anterior cruciate ligament injury in female athletes: epidemiology. *J Athl Train.* 1999;34(2):150-154.
3. de Loes M, Dahlstedt LJ, Thomee R. A 7-year study on risks and costs of knee injuries in male and female youth participants in 12 sports. *Scand J Med Sci Sports.* 2000;10(2):90-97.
4. Arendt EA, Agel J, Dick R. Anterior cruciate ligament injury patterns among collegiate men and women. *J Athl Train.* 1999;34(2):86-92.
5. Freedman KB, Glasgow MT, Glasgow SG, Bernstein J. Anterior cruciate ligament injury and reconstruction among university students. *Clin Orthopaed Rel Res.* 1998(356):208-212.
6. Kamath GV, Murphy T, Creighton RA, Viradia N, Taft TN, Spang JT. Anterior Cruciate Ligament Injury, Return to Play, and Reinjury in the Elite Collegiate Athlete: Analysis of an NCAA Division I Cohort. *Am J Sports Med.* 2014;42(7):1638-1643.
7. Webster KE, Feller JA, Leigh WB, Richmond AK. Younger patients are at increased risk for graft rupture and contralateral injury after anterior cruciate ligament reconstruction. *Am J Sports Med.* 2014;42(3):641-647.
8. Ford KR, Myer GD, Toms HE, Hewett TE. Gender differences in the kinematics of unanticipated cutting in young athletes. *Med Sci Sports Exerc.* 2005;37(1):124-129.
9. McLean SG, Walker KB, van den Bogert AJ. Effect of gender on lower extremity kinematics during rapid direction changes: an integrated analysis of three sports movements. *J Sci Med Sport.* 2005;8(4): 411-422.
10. McLean SG, Lipfert SW, Van Den Bogert AJ. Effect of Gender and Defensive Opponent on the Biomechanics of Sidestep Cutting. *Med Sci Sports Exerc.* 2004;36(6):1008-1016.
11. Hewett TE, Myer GD, Ford KR, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med.* 2005;33(4):492-501.
12. Olsen OE, Myklebust G, Engebretsen L, Bahr R. Injury mechanisms for anterior cruciate ligament injuries in team handball: a systematic video analysis. *Am J Sports Med.* 2004;32(4):1002-1012.
13. Koga H, Nakamae A, Shima Y, et al. Mechanisms for noncontact anterior cruciate ligament injuries: knee joint kinematics in 10 injury situations from female team handball and basketball. *Am J Sports Med.* 2010;38(11):2218-2225.
14. Hewett TE, Torg JS, Boden BP. Video analysis of trunk and knee motion during non-contact anterior cruciate ligament injury in female athletes: lateral trunk and knee abduction motion are combined components of the injury mechanism. *Br J Sports Med.* 2009;43(6):417-422.
15. Krosshaug T, Nakamae A, Boden BP, et al. Mechanisms of anterior cruciate ligament injury in basketball: video analysis of 39 cases. *Am J Sports Med.* 2007;35(3):359-367.
16. Leetun DT, Ireland ML, Willson JD, Ballantyne BT, Davis IM. Core Stability Measures as Risk Factors for Lower Extremity Injury in Athletes. *Med Sci Sports Exerc.* 2004;36(6):926-934.
17. Heinert BL, Kernozek TW, Greany JF, Fater DC. Hip abductor weakness and lower extremity kinematics during running. *J Sport Rehab.* 2008;17(3):243-256.
18. Stearns KM, Powers CM. Improvements in hip muscle performance result in increased use of the hip extensors and abductors during a landing task. *Am J Sports Med.* 2014;42(3):602-609.
19. Claiborne TL, Armstrong CW, Gandhi V, Pincivero DM. Relationship between hip and knee strength and knee valgus during a single leg squat. *J Appl Biomech.* 2006;22(1):41-50.

20. Willson JD, Ireland ML, Davis I. Core strength and lower extremity alignment during single leg squats. *Med Sci Sports Exerc.* 2006;38(5):945-952.
21. Baldon Rde M, Lobato DF, Carvalho LP, Santiago PR, Benze BG, Serrao FV. Relationship between eccentric hip torque and lower-limb kinematics: gender differences. *J Appl Biomech.* 2011;27(3):223-232.
22. Stickler L, Finley M, Gulgin H. Relationship between hip and core strength and frontal plane alignment during a single leg squat. *Phys Ther Sport.* 2015;16(1):66-71.
23. McCurdy K, Walker J, Armstrong R, Langford G. Relationship between selected measures of strength and hip and knee excursion during unilateral and bilateral landings in women. *J Strength Cond Res.* 2014;28(9):2429-2436.
24. Jacobs CA, Uhl TL, Mattacola CG, Shapiro R, Rayens WS. Hip abductor function and lower extremity landing kinematics: sex differences. *J Athl Train.* 2007;42(1):76-83.
25. Thijs Y, Van Tiggelen D, Willems T, De Clercq D, Witvrouw E. Relationship between hip strength and frontal plane posture of the knee during a forward lunge. *Br J Sports Med.* 2007;41(11):723-727.
26. Sigward SM, Ota S, Powers CM. Predictors of frontal plane knee excursion during a drop land in young female soccer players. *J Orthopae Sports Phys Ther.* 2008;38(11):661-667.
27. Hollman JH, Ginos BE, Kozuchowski J, Vaughn AS, Krause DA, Youdas JW. Relationships between knee valgus, hip-muscle strength, and hip-muscle recruitment during a single-limb step-down. *J Sport Rehab.* 2009;18(1):104-117.
28. Magalhaes E, Fukuda TY, Sacramento SN, Forgas A, Cohen M, Abdalla RJ. A comparison of hip strength between sedentary females with and without patellofemoral pain syndrome. *J Orthopaed Sports Phys Ther.* 2010;40(10):641-647.
29. Thorborg K, Petersen J, Magnusson SP, Holmich P. Clinical assessment of hip strength using a hand-held dynamometer is reliable. *Scand J Med Sci Sports.* 2010;20(3):493-501.
30. Neumann DA. Kinesiology of the hip: a focus on muscular actions. *J Orthopaed Sports Phys Ther.* 2010;40(2):82-94.
31. Myer GD, Ford KR, McLean SG, Hewett TE. The effects of plyometric versus dynamic stabilization and balance training on lower extremity biomechanics. *Am J Sports Med.* 2006;34(3):445-455.
32. Bisseling RW, Hof AL. Handling of impact forces in inverse dynamics. *J Biomech.* 2006;39(13):2438-2444.
33. OP S, C J, CG M, TL U, DL J. Hip abduction and adduction strength of injured and healthy collegiate football athletes. *J Athl Train.* 2005;40(supplyment):S-73.
34. Thorborg K, Bandholm T, Petersen J, et al. Hip abduction strength training in the clinical setting: with or without external loading? *Scand J Med Sci Sports.* 2010;20 Suppl 2:70-77.
35. Thorborg K, Bandholm T, Holmich P. Hip- and knee-strength assessments using a hand-held dynamometer with external belt-fixation are inter-tester reliable. *Knee Surg Sports Traumatol Arthrosc.* 2013;21(3):550-555.