A COMPARISON OF WEIGHT-BEARING VERSUS TRADITIONAL HIP STRENGTH ASSESSMENT

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ABSTRACT

A Comparison of Weight-Bearing and Traditional Hip Strength Assessments  
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Context: Hip strength assessment in a weight-bearing (WB) position has been  
advocated to be an alternative and more meaningful method of muscles testing  
compared to traditional non-weight-bearing (NWB) assessments. Though shown to be  
reliable, no other studies have examined the differences between WB and NWB  
strength.

Objective: To determine the hip strength differences between WB assessments and  
NWB assessments in healthy female athletes.

Design: Prospective experimental study.

Setting: University Laboratory.

Patients: Female athletes (N=51, 16.2 ± 3.5 years, ranged 12-25 years old, 161.5 ±  
8.32 cm, 58.3 ± 11.6 kg) that participated in soccer, basketball, and volleyball, were  
recruited from local universities and high schools.

Interventions: Hip strength was quantified by a single examiner (AU) using two  
MicroFET2 handheld dynamometers (HHDs) to determine force (N). The WB  
assessments was conducted to test the hip abductor and external rotator strength in a  
standing double-leg squat and lunge position. Two HHDs was simultaneously utilized  
only in the squat unilaterally (SQ-U) and lunge (LNG) assessments. The NWB assessments was conducted to  
individually test hip abduction (HAB), extension (HEXT), and external rotation (HER)  
strength. A break test was performed with the valgus force applied proximal to the knee  
for all strength assessments besides the HEXT assessment. The peak strength of three  
trials was normalized to body mass (N/kg).

Main Outcome Measures: Data met t-test assumptions. Each WB assessment (SQ-B, SQ-U, LNG) were separately compared to each NWB assessment (HAB, HEXT, HAB) in order to evaluate the differences in a matched pairs t-test (t) with effect size (d) to determine the difference magnitude. A Pearson’s Product-Moment Correlation Coefficients (r) was calculated to determine the correlation between the WB and NWB assessments.

Results: Significant differences was observed between the WB and NWB  
assessments, except for the right leg SQ-U and HER (t=1.83, p=0.07, d=0.24). Conversely, participants were significantly weaker in the LNG versus NWB  
assessments. Significant correlations between WB and NWB assessments ranged from  
low to moderate (r=0.28 to 0.58) when examining the right and left leg.

Conclusions: The results of our study demonstrate that there is a difference between  
the WB and NWB hip strength assessments. The low to moderate correlations  
demonstrates different hip muscle patterns. We recommend the SQ-B assessment to  
evaluate the hip abductor and external rotator in WB position. This information is  
important to consider as it demonstrates that the gluteus maximus provides dynamic  
stability in the WB assessment and provide unique information from an injury prevention  
and treatment perspective.  Word Count: 412
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Introduction

Functional hip strength is important during athletic movements, such as landing and cutting in soccer and basketball. Impaired or weakened hip muscles, specifically the hip abductors and external rotators, are associated with abnormal lower extremity biomechanics\textsuperscript{1-5} and are contributing factors in iliotibial band stress syndrome\textsuperscript{6}, patellofemoral joint dysfunction\textsuperscript{7,8}, and anterior cruciate ligament injury\textsuperscript{9,10}. The gluteus medius and gluteus maximus contract to maintain proper hip and knee dynamic stability\textsuperscript{5,11} by eccentrically limiting hip flexion, adduction, and internal rotation\textsuperscript{11,12}. Inability of the hip abductors and external rotators to provide dynamic stability may result in dynamic valgus of the knee\textsuperscript{5}, which increases knee injury risk\textsuperscript{8,13}. Therefore, ensuring active individuals possess adequate hip strength is essential to clinicians for injury prevention and rehabilitation.

Previous studies have reported low to moderate correlations between hip strength and detrimental knee kinematics during a single-leg squat\textsuperscript{3,13}, single-leg landing task\textsuperscript{2,14-16}, double-leg landing task\textsuperscript{16}, and running\textsuperscript{17}. While these studies support the idea that hip strength may have a role dynamic stability of the knee, other studies have found no significant correlations between hip strength and knee kinematics during the double-leg landing task\textsuperscript{18} or a lunging task\textsuperscript{19}. Even more concerning is that some studies have found a significant and positive correlations between greater hip strength and decreased knee valgus during a double-leg landing task\textsuperscript{20} and single-leg step-down\textsuperscript{1}. The inconsistencies and suboptimal correlations across previous studies may be due to methodological differences in hip strength testing. These studies assessed strength in an open-kinetic-chain (OKC) position, which involves the patient on a table.
and the leg not in contact with the ground. Given that muscles contract differently during OKC than in closed-kinetic-chain (CKC) activities\textsuperscript{21}, it is possible that previous studies did not accurately collect strength data in a manner that reflects how the muscles function during the WB testing. These possibly invalid muscle testing position may have affected the results for their injury risk prediction models.

Recently, Lee et al. proposed a weight-bearing assessment to quantify hip abductor and external rotator strength\textsuperscript{22}. They demonstrated the weight-bearing assessment in a CKC position to be more reliable than traditional non-weight-bearing assessment in the side-lying position for hip abduction, while also being moderately correlated to the NWB assessment\textsuperscript{22}. Based on these findings, it seems plausible that CKC muscle strength testing may have additional clinical utility in knee injury risk assessment, especially considering the previously mentioned issues found using OKC muscle strength testing. However, a further examination of the differences in strength between test positions is warranted to ensure that the weight-bearing testing positions are providing different and unique information compared to the OKC testing.

Therefore, the purpose of this research study was to compare the hip abductor and external rotator strength between weight-bearing (WB) assessments and the traditional non-weight-bearing (NWB) assessments in healthy active female athletes. Specifically, we investigated testing positions that targeted the strength values of the gluteus maximus and gluteus medius to resist dynamic valgus. Secondarily, we determined the correlations between the WB and NWB hip strength assessments.
Methodology

Participants

Fifty-one female athletes (N=51, 16.2 ± 3.5 years, ranged 12-25 years old, 161.5 ± 8.32 cm, 58.3 ± 11.6 kg) that participated in soccer (n=36), basketball (n=14), and volleyball (n=1) were recruited from the local universities (n=18) and high schools (n=33). Participants completed the Physical Activity Readiness Questionnaire (PAR-Q) to screen for recent inactivity or serious medical conditions. Exclusionary criteria included a history of knee surgery or a lower extremity injury in the past six months that caused a reduction in physical activity. All the participants and legal guardians provided informed consent and assent in accordance with the University Human Studies Program.

Procedures and Instrumentation

Participants came to the University of Hawai‘i Human Performance Lab for a single data collection that lasted approximately one hour. Anthropometric data was collected utilizing a wall-mounted stadiometer (Seca Telescopic Stadiometer, Gays Mills, WI, USA) to obtain height and a calibrated scale (Detecto Inc., Webb City, MO, USA) for body mass. Each participant performed a five-minute self-selected warm-up on a stationary bicycle. Hip strength was quantified by a single examiner (AU) using two microFET 2 handheld dynamometers (HHD) to determine force (N). Intra-rater reliability of the examiner and inter-rater reliability of the two HHDs was conducted from a pilot study (n=10). Intraclass correlation coefficient (ICC) and standard error of the mean (SEM) was obtained for the WB and NWB hip strength assessments. For the intra-rater reliability of the examiner, the WB hip strength assessments reported an ICC
ranging from 0.70 to 0.88 (SEM, 0.19-0.41) and the NWB hip strength assessments reported an ICC ranging from 0.72 to 0.89 (SEM, 0.36-0.45). The inter-rater reliability of the HHDs, the WB hip strength assessments reported an ICC ranging from 0.40 to 0.59 (SEM, 0.46-0.53) and the NWB hip strength assessments reported an ICC ranging from 0.55 to 0.88 (SEM, 0.38-0.76).

The WB assessments were performed initially, then the traditional NWB assessments followed. Two HHDs were utilized simultaneously during the bilateral WB squat assessment and a single HHD was used for the other hip assessments. A break test that has been shown to be reliable and appropriate for hip strength assessments was performed on the dominant leg for all strength assessments\textsuperscript{23,24}. Each participant performed submaximal trials before the assessment to ensure correct positioning and familiarization with the assessment. A 90-second rest was given between each trial and assessment to avoid fatigue. Use of adjacent muscles or deviation from the intended motion was monitored and corrected if observed. Verbal encouragement and force feedback was given to facilitate a maximal effort. The greatest force production out of three trials was normalized to body mass (N/kg) and used for further statistical analyses.

Weight-Bearing Assessments

The WB assessments were conducted in a standing squat and lunge position with a valgus force applied proximal to the tested knee. The resistance to valgus was simultaneously evaluated during a squat bilaterally (SQ-B), unilaterally (SQ-U) in a squat, as well as in a lunge (LNG), respectively. For the standing squat position, participants stood in 30° of hip flexion and 50° of knee flexion with neutral lumbar
lordosis, feet parallel and shoulder width apart with the arms folded across their chest. This position is moderately correlated \((r=0.75, p<0.01)^{22}\) with the traditional side-lying hip abduction position, but showed a greater test-retest reliability \((\text{ICC}=0.99)^{22}\) compared to Widler et al\(^{25}\) \((\text{ICC}=0.90)\).

For the LNG position, participants stood with their feet position at a distance of 60% of their height and 60° of knee flexion. The non-tested leg was externally rotated to provide stability and prevent the heel from raising. Participants were instructed to maintain their feet shoulder width apart and arms fold across their chest. This position is based on increasing the muscular demands of the gluteus maximus.\(^{26}\)

**Non-Weight-Bearing Assessments**

The NWB assessments were conducted in the following order: hip external rotation (HER), extension (HEXT), and abduction (HAB). The HHD was positioned just proximal to the lateral epicondyle of the tested leg for all the NWB assessments. The starting position for HER was in a side-lying clam position with both legs at 45° of hip flexion and 90° of knee flexion. Both feet were positioned together and lined parallel with the long axis of the torso. Participants were instructed to raise up the tested knee in 30° of hip abduction while keeping the feet together. This position demonstrates the best superior gluteus maximus activity as a hip abductor and external rotator while minimizing the tensor fascia latae.\(^{27}\)

The starting position for HEXT was in a standing-prone position at 60° of hip flexion. Participants were instructed to extend the tested leg until parallel to the long axis of the torso, then they were placed in 30° of abduction, 20° of external rotation and 90° of knee flexion. The non-test leg was in contact with the floor with the knee slightly
bent for stability. This position elicits the greatest gluteus maximus activity as a hip extensor and external rotator versus a prone position\textsuperscript{28}, while also minimizing the muscular activity of the hamstring and lower back musculature\textsuperscript{29,30}.

The starting position for HAB was in a side-lying position with the non-test leg in 30° of hip and knee flexion and the test leg parallel with the long axis of the torso. Participants were instructed to raise the test leg up in 10° of abduction. This position elicits a maximum contraction for the gluteus medius as a hip abductor\textsuperscript{25}.

**Statistical Analyses**

Means and standard deviations of all the key variables were computed and reported (Table 1.). Levene’s Test for Homogeneity of Variances was determined and non-significant for all dependent variables. For WB assessments, the values of the right leg were compared to the right leg of the NWB assessments, and vice-versa for the left leg. Two-tailed matched pairs $t$-tests were used to evaluate the difference between WB and NWB hip strength (N/kg) with effect size ($d$) calculated to determine the magnitude of difference between variables. Pearson’s Product-Moment Correlation Coefficients were calculated to determine the correlations between the WB and NWB assessments. All statistical analyses were performed using SPSS Statistical Software 22.0 (SPSS, Inc., Chicago, IL.) with statistical significance established at $\alpha \leq 0.05$.

**Results**

Comparison of the WB and NWB hip strength assessments are reported in Table 1. along with significant differences observed between the WB and NWB assessments, except for the right leg SQ-U and HER ($t=1.83$, $p=0.07$, $d=0.24$). The largest effect size differences were found comparing SQ-B to the NWB assessments for right HER
HEXT (t=19.38, p<0.001, d=3.36), HAB (t=14.29, p<0.001, d=2.32), and the left HER (t=10.57, p<0.001, d=1.53), HEXT (t=16.56, p<0.001, d=2.47), HAB (t=11.31, p<0.001, d=1.74) (Figure 1). When examining the SQ-U to the NWB assessments, significant differences in HEXT (t=8.94, p<0.001, d=1.40), and HAB (t=2.64, p=0.01, d=0.39) were found on the right leg and HER (t=4.30, p<0.001, d=0.58), HEXT (t=12.08, p<0.001, d=1.64), HAB (t=6.67, p<0.001, d=0.90) on the left leg (Figure 1). Conversely, participants were significantly weaker in the LNG versus NWB assessments (Figure 1). We found large effect size differences in HER (t=-13.35, p<0.001, d=-2.28), HEXT (t=-8.16, p<0.001, d=-1.42), HAB (t=-9.92, p<0.001, d=-1.79) on the right leg and HER (t=-15.00, p<0.001, d=-2.58), HEXT (t=-10.78, p<0.001, d=-1.49), HAB (t=-10.03, p<0.001, d=-1.79) on the left leg.
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\(^a\) Significantly different from the WB assessment (p<0.05)  
\(^b\) Significantly different from the WB assessment (p<0.001)

Abbreviations: WB=weight-bearing, NWB=non-weight-bearing, HER=hip external rotation, HEXT=hip extension, HAB=hip abduction, SQ-B=bilateral standing squat, SQ-U=unilateral standing squat, LNG=lunge  
Each WB assessments (SQ-B, SQ-U, LNG) were separately compared to each NWB assessments (HER, HEXT, HAB).
Correlations between WB and NWB assessments ranged from low to moderate when examining the right and left leg (Table 2). When examining the relationship between SQ-B to the NWB assessments, significance was found for right HER ($r=0.46$, $p=0.001$), HAB ($r=0.33$, $p=0.018$) and left HER ($r=0.47$, $p<0.001$), HEXT ($r=0.45$, $p=0.001$) and HAB ($r=0.39$, $p=0.004$). Low and moderate correlations of significances were found comparing SQ-U to the NWB assessments for the right HER ($r=0.58$, $p<0.001$), HEXT ($r=0.38$, $p=0.007$) and HAB ($r=0.47$, $p<0.001$) and for the left HER ($r=0.54$, $p<0.001$), HEXT ($r=0.53$, $p<0.001$), and HAB ($r=0.55$, $p<0.001$). When examining the LNG to the NWB assessments, significance was found in HER ($r=0.30$, $p=0.031$) on the right leg and HER ($r=0.28$, $p=0.045$) and HEXT ($r=0.57$, $p<0.001$) on the left leg.
Discussion

The purpose of this study was to compare hip abductor and external rotator strength between the WB and NWB assessments in female athletes. The results indicate that female athletes produced the greatest force during a WB squat assessment compared to the traditional NWB assessments. In addition, the LNG produced the lowest strength values compared to all the other strength assessments. The strength values measured in the WB assessment significantly correlated with the values obtained in the HER and HAB assessments. A significant and moderate correlation was observed in the HER assessment for the SQ-B and SQ-U assessments. The low to moderate correlation of the standing squat (SQ-B and SQ-U) and NWB assessments further demonstrates the difference between the WB and NWB assessments.

The strength values observed in our study for the WB assessments were different than those reported by Lee et al. (2.6 ± 0.5 N/kg) for their WB hip abductor and external rotator test in females\textsuperscript{22}. The strength values observed in our study was 58%
and 49% greater for the right and left legs during the SQ-B, respectively. The SQ-U assessment were 37% and 39% greater for the right and left leg, respectively. The differences in results might be due to the variation in the assessments between the two studies. The standing squat position of the WB assessments in both studies were the identical, however Lee et al. quantified strength using a force transducer connected to a non-stretchable fabric strap and instructed participants to push outwards as hard as possible in a concentric “make test”\textsuperscript{22}. In our study, hip abductor and external rotator strength were quantified using HHDs with participants being instructed to resist a proximal valgus force to their knees from going inwards in an eccentric break test. A break test would increase the demands of the hip abductor and external rotators from going inwards and producing a greater strength value compared to “make tests”\textsuperscript{23,31}. It can be argued that the standing squat position of the WB assessment challenged the participants to resist their knees going inwards more so than pushing their knees outwards would have.

The LNG assessment demonstrated the lowest strength value, as this difference is likely due to the need to create a more stable base for support. The resulting tandem stance in the LNG assessment presents a challenge for balance on the forward foot due to the feet being longer compared to their width. Additionally, the gluteus maximus and medius may not be aligned to eccentrically resist the knee from going into knee valgus. The gluteus maximus is a strong hip extensor in the sagittal plane and external rotator in the transverse plane\textsuperscript{11}. Delp et al. found that the gluteus maximus has a large capacity for external rotation when the hip is at 0° extension; however, as the hip is flexed past 45°, the superior fibers switch from external rotation to an internal rotation
moment arm. The inferior fibers of the gluteus maximus remains an external rotator throughout the range of hip flexion but has a reduced moment arm. The gluteus medius is primarily a hip abductor in the frontal plane, but does contribute to extension in the sagittal plane and either internal or external rotation in the transverse plane. Like the superior fibers of the gluteus maximus, the gluteus medius switches from an external rotation to internal rotation moment arm during hip flexion past 30°. In the LNG, the hip is in a flexed position as participants lunged forward to 60% of their height with the knee flexed to 60°, consequently the gluteus maximus and medius may not have the adequate moment arm to counteract the external force. This could explain the results of the LNG assessment demonstrating the largest negative effect sizes compared to the NWB assessment.

Significance was found between the correlations of both the WB squat assessments and the HAB and HER assessments. For the HAB assessment, a low positive correlation of \( r=0.33 \) (\( p<0.05 \)) and \( r=0.39 \) (\( p<0.05 \)) for the right and left leg of the SQ-B assessment was found. In addition, a slightly higher correlation for the HAB assessment was found for the right (\( r=0.47, p<0.001 \)) and left (\( r=0.55, p<0.001 \)) leg of the SQ-U assessment. Lee et al. reported a significant position correlation (\( r=0.75, p<0.01 \)) with their hip strength values between their WB hip abductor and external rotator test and NWB hip abduction test. The reported significant positive correlation in our study were lower than what Lee et al. reported. Anatomically, the gluteus medius functions to stabilize the head of the femur within the acetabulum, act as a hip abductor and external rotator and assist with initiating the weight shift during walking. It can be argued that in our study, the WB squat assessments reported
greater hip strength values and lower correlations compared to the results reported by Lee et al. may be explained to the changing function of the gluteus medius as a pelvic stabilizer to maintain the head of the femur within the acetabulum in an eccentric contraction.

A moderate significant correlation was found between the SQ-B assessment and HER assessment for the right \( r=0.46, p<0.05 \) and left \( r=0.47, p<0.001 \) leg. For the SQ-U and HER assessment, a moderate correlation of \( r=0.58, p<0.001 \) and \( r=0.54, p<0.001 \) for the right and left leg was reported, respectively. The HER assessment was based on the side-lying clam position in which, Selkowitz et al. observed a mean electromyography activity using fine-wire electrodes that targeted the superior gluteus maximus at 43.6 ± 26.1%, gluteus medius at 26.7 ± 18.0%, and tensor fascia lata at 11.4 ± 11.4% maximum voluntary contraction\(^{27}\). Anatomically, the gluteus maximus is the largest muscle in the hip and the most potent external rotator\(^{11}\) with the superior fibers contributing to hip abduction and inferior fibers contributing to hip extension.

Based on the electrographic activity of the gluteus maximus in the standing squat position, side-lying clam position of the HER assessment and anatomic findings of the gluteus maximus, the greater and more significant correlations suggest that the gluteus maximus is aligned to effectively react to the to the external forces of the knee going into valgus while the gluteus medius act as a pelvic stabilizer during a WB hip strength assessment.

The low to moderate correlations may support the function and role of gluteus maximus and medius in a CKC position; however, the low to moderate correlation may further explain the difference between WB and NWB hip strength assessment. A lower
correlation trends towards having no relationship. Given the nature of all the assessments to activate the gluteus maximus and medius, it seems a higher correlation would likely occur between the WB and NWB assessments. In contrast, the low to moderate correlation may demonstrate the lack of relationship due to the behavior of the gluteus maximus and medius in a CKC position. Previous studies have demonstrated greater hip abductor activation level in the WB stance leg compared to the active hip abduction leg in a CKC position of hip strength assessment\textsuperscript{21,25}. This suggests a different hip muscle pattern in the WB assessments that may not be evident in the NWB assessments. The LNG assessment does not appear to be an optimal position for hip abduction and external rotation strength assessment because of the difficulties of balance and the gluteus maximus and medius to effectively resist the external valgus force. The findings of the study demonstrate the difference between the WB and NWB assessments; therefore, the SQ-B assessment is recommended to assess hip abductor and external rotator strength.

There are limitations to this study. The results of this study involve high school and collegiate female athletes that participated in soccer, basketball, or volleyball. This may limit the generalization of the results to other populations and may be unique to female athletes. Electromyography activity was not measured in this study; therefore, it was not possible to measure the activation of either the gluteus maximus or medius for each hip strength assessment. However, assessments positions were chosen based on the previous research that yielded the highest electromyography activity of either the gluteus maximus or medius.

**Conclusion**
The results of our study demonstrate that there are sizeable differences between the WB hip strength assessment and traditional NWB hip strength assessments. The low to moderate agreement of the WB assessment and NWB assessment may explain the contributing strength of the gluteus maximus in the WB assessment. More so, the low to moderate correlation suggest a different hip muscle pattern in a WB assessment. We recommend the SQ-B assessment to evaluate the hip abductor and external rotator strength. These findings present a potential link to how the gluteus maximus and medius may interact during CKC activities and provide unique information from an injury prevention and injury risk prediction models.
Kinesiology of the Gluteus Maximus and Medius

The gluteus maximus is the largest muscle in the hip and consider primarily a hip extensor and external rotator\(^\text{11}\). The proximal attachment occurs at the superolateral area of the posterior ilium down to the coccyx; which includes, the gluteus medius fascia, ilium and posterior layer of lumbar fascia, erector spinae aponeurosis, dorsal sacroiliac ligament, sacrum, sacrotuberous ligament and coccyx\(^\text{35}\). The distal attachment inserts on the lateral tibial condyle (Gerdy’s tubercle) via the iliotibial tract and lateral retinaculum. The fiber direction of the gluteus maximus ranges from 32° to 45° with the more horizontal fibers having an increased capacity for compressive force at the sacroiliac joint and the lower fibers generating more of hip extension\(^\text{35}\). At 0° of hip flexion, all the fibers of the gluteus maximus have a moment arm of external rotation\(^\text{12}\). As the hip flexes, the more horizontal fibers switch from an external rotation moment to an internal rotation moment\(^\text{12}\). As the hip is flexed from 0° to 60°, the moment arm for hip extension of the gluteus maximus increases\(^\text{12}\).

The fan-shaped gluteus medius is the largest hip abductor, accounting for about 60% of the total abductor muscle cross-sectional area\(^\text{11}\). Primarily, the gluteus medius is a hip abductor; and secondarily a hip extensor, internal and external rotator\(^\text{11}\). Due to the innervation of the gluteus medius, the muscle is separated in four compartments: anterior, mid-anterior, mid-posterior, and posterior\(^\text{32}\). The proximal attachments occur at three sites: the main site was at the gluteal fossa extending from the posterior sacroiliac ligaments along the posterior gluteal line posteriorly to the anterior superior iliac spine. The secondary sites were the deep surface of the gluteal aponeurosis and the
posteroinferior edge of the iliac crest.\textsuperscript{32} The distal attachments occurs at the greater trochanter with some fibers along the anteroinferior oblique line on the lateral aspect of the greater trochanter.\textsuperscript{32} From these attachments, the anterior compartment tends to overlap the middle compartment and subsequently with the middle and posterior compartment.\textsuperscript{32,33} The anterior compartment run almost vertically from the anterior iliac crest to the greater trochanter while the posterior compartment is parallel to the femoral neck.\textsuperscript{34} From the anatomical position, all the compartments of the gluteus medius produce an abduction moment.\textsuperscript{11,12,34} At $0^\circ$ of hip flexion, the anterior compartment has a small internal rotation moment arm and the posterior compartment has an external rotation moment arm. As the hip is flexed, the anterior compartment increases and the posterior compartment remains an external rotation moment arm; however, reduces towards an internal rotation moment arm\textsuperscript{12}.

\textit{Anatomy of the Gluteus maximus}

Barker et al. investigated the proximal attachment of the gluteus maximus to document the anatomical features to estimate the force generation at the sacroiliac joint and lumbar spine.\textsuperscript{35} Six embalmed cadavers were dissected to document fascicle orientation, length, and volume. Fascicle was defined as a bundle of muscle fibers surrounded by perimysium. The length was removed from the cadaver between their myotendinous junction and laid straight for measurement while volume was calculated by placing the tissue in a 500-mL volumetric cylinder and observed the water displacement for measurement. Proximal attachment of the gluteus maximus include the gluteus medius fascia, ilium and posterior layer of lumbar fascia, erector spinae aponeurosis, dorsal sacroiliac ligaments, sacrum, sacrotuberous ligament and coccyx.
The mean fascicle orientation ranged from $32^\circ$ to $45^\circ$ of the upper and middle attachment points. Distal attachment occurred into the iliotibial band over the greater trochanter and into the gluteal tuberosity. Greatest length took place between the sacral and coccyx and the least length arising from the gluteus medius fascia. The physiological cross-sectional area was measured to obtain an estimate force generation. The average total physiological cross-sectional area of the gluteus maximus was 26 centimeter squared in which 70% crossed the sacroiliac joint.\textsuperscript{35}

Stecco et al. examined the distal attachment of the gluteus maximus in order better understand the relationship between the muscular fibers insertion into the fascia lata, iliotibial tract and lateral intermuscular septum\textsuperscript{36}. The posterior side of the thigh of six cadavers (four males and two females) were dissected. The superficial fascia layer of the gluteus maximus was continuous with the posterior lamina of the thoracolumbar fascia and 1) distally, it runs with the fascia lata and iliotibial tract, 2) medially, it adheres to the periosteum of the sacrum and 3) laterally, it continues with the fascia of the tensor fascia lata muscle. The fascia lata reveals a thicker region in the lateral and posterolateral aspect called the iliotibial tract. The iliotibial tract is a lateral reinforcement of the fascia lata. Particularly, the muscle fibers of the gluteus maximus insert into the iliotibial tract and into the lateral intermuscular septum. Intermittent, some muscular fibers of the gluteus maximus merged with the aponeurotic portion of the vastus lateralis muscle. Distal attachment of the iliotibial tract attached to the lateral condyle of the tibia (Gerdy’s tubercle) and contribute to the lateral anterior knee retinaculum of the patella as an oblique myofascial expansion. Stecco et al. concluded
the gluteus maximus to be an important structure for knee movement due to the distal insertions of the iliotibial tract.\textsuperscript{36}

\textit{Anatomy of the Gluteus medius}

Gottschalk et al. investigated the functional anatomy of the hip abductor and described the mechanism to correlate the findings with a biomechanical model\textsuperscript{34}. Eleven cadavers (six fresh and five preserved) were dissected in the gluteal region retaining the pelvis and proximal femur. Based on the anatomical findings, a new biomechanical model was developed and explained through a previously corroborated study by Kadaba, Wootten, Gainey and Cochran, 1985. These research authors conducted an electromyographic study of the hip abductors in ten normal subjects during the gait cycle and hip abduction of the lower extremity. Gottschalk et al. described the proximal attachment of the gluteus medius to be from the anterior superior iliac spine, along with the outer edge of the iliac crest to the posterior superior iliac spine. Distal attachment of the tendon inserted to the anterosuperior portion of the greater trochanter to create a curved and fan-shaped gluteus medius. Three distinct parts were equal in volume and division were observed in fresh specimens. The anterior portion had fibers running almost vertical from the top of the trochanter to the anterior iliac crest. Similar, the middle portion had fibers more vertically orientated. The posterior portion had fibers running parallel to the femoral neck. The superior gluteal nerve emerged from the greater sciatic notch and provided separate branches to each of the three parts of the gluteus medius and several different branches to the gluteus minimus and tensor fascia latae. More commonly, variations occurred with the branch of the posterior part of the gluteus medius arising in the sciatic notch.
Based on these findings and the results from the electromyographic study, the Gottschalk et al. defined the gluteus medius and minimus primarily as a hip stabilizer and pelvic rotators. The gluteus medius secondary function to initiate and assist in hip abduction. The primary function of hip abduction occurred due to activity in the tensor fascia latae muscle. The anterior and middle portions of the gluteus medius provided a more vertical pull to assist in initiate abduction in which coincident with the initiation of pelvic rotation. Due to the anatomical configuration of the three parts of the gluteus medius, the research authors postulated the gluteus medius and minimus as stabilizers of the hip during the weight-bearing phase of the gait cycle and act as pelvic rotators for the swing phase of the gait cycle.\textsuperscript{34}

Al-Hayani, A. examined the gluteal region in eighteen adult cadavers to establish the attachment and fiber directions of the hip abductors to understand their role to support the body and in the gait cycle\textsuperscript{33}. The gluteus medius, gluteus minimus and tensor fasciae latae muscles were dissected from eighteen adult cadavers (36 gluteal regions, 18 right and 18 left). The shapes of the muscles along with the attachments and fiber direction were determined by tracing the superior gluteal nerve and its branches from the greater sciatic notch. An anterior, middle and posterior compartment are distinct in the gluteus medius. Each part was different size with the anterior part being the largest. Their proximal attachment was found on the outer surface of the ala of the ilium, in between the iliac crest, above the posterior gluteal line, below the anterior gluteal line, and from the overlying deep fascia. The anterior part overlapped the middle and posterior compartments with the fibers running vertically from the ala of the ilium to the ridge on the greater trochanter on the lateral aspect. The middle
compartment overlapped the posterior compartment with the fibers running more vertically, and the fibers of the posterior compartment were parallel to the neck of the femur. The inferior division of the superior gluteal nerve traveled in between the gluteus medius and minimus and provided branches for the three distinct parts of the gluteus medius and to the two parts of the gluteus minimus. The branches of the superior gluteal nerve to the posterior compartment of the gluteus medius frequently appeared in the greater sciatic notch. The projection line of action for the anterior and middle compartment showed the fibers run vertically from the ala of the ilium to the greater trochanter. The projection line of action of the posterior compartment showed the fibers run parallel to the axis of the neck of the femur from the ala of the ilium to the greater trochanter. Al-Hayani, A. suggested the primary function the posterior compartment of the gluteus medius and minimus are to stabilize the femoral head in the acetabulum during various stages of the gait cycle.  

Flack et al. explored the specific anatomical features of the hip abductor muscles and established how these muscles could be divided into different compartments. Twelve cadavers were dissected in the gluteal region to provide the measurements of structural parameters. These structural parameters include; gross muscle morphology, fascicle morphology, anatomical partitioning, atrophy and tendon morphology. In this review, the gluteus medius was primarily reviewed. Flack et al. concluded when considering the primary innervation pattern and one or more of the structural characteristics of the gluteus medius. The gluteus medius is divided into four anatomical compartments; anterior, mid-anterior, mid-posterior and posterior. The anterior compartment significantly had more fascicles, larger volume, and physiological
cross-sectional area. The gluteus medius origin was identified in three regions. The main site was in the gluteal fossa extending from the posterior sacroiliac ligaments and along the body of the ilium between the posterior and anterior gluteal line then thinning to the anterior superior iliac spine. The secondary sites were the deep surface of the gluteal aponeuroses of the gluteus maximus, superior portion of the gluteus medius and the posteroinferior edge of the lip of the iliac crest. The posterior aspect of the gluteus medius became a cord-like aponeurotic tendon thickening attaching posteriorly to the greater trochanter. The remainder of the aponeurotic tendon crossed the greater trochanter and inserted along an anteroinferior oblique line on the lateral aspect of the greater trochanter. Based on the orientation of the posterior fibers with the distribution of the nerve branches, the gluteus medius function to concentrically external rotation and abduction then eccentrically control internal rotation and adduction of the hip joint. Neumann, D. reviewed the muscular actions of the muscle in the hip through several discussions associated with the muscular kinesiology; including, muscle torque potential, moment arm, cross-sectional area, overall fiber direction and line of force about an axis of rotation. Extensive data was highlighted by literature reviewed by Dostal et al.; however, the data only represents one male cadaver specimen in the anatomic position. In the discussion, the line of force along with muscle torque was discussed in three cardinal planes of motion of the hip: sagittal, horizontal and frontal. Each plane of motion, the muscle’s actions were based on the orientation of its line of force about the joint’s axis of rotation. Muscle line of force was represented by a straight line between the attachment points. Therefore, muscle action was described as

*Muscular action potential of the Gluteus Maximus and Medius*

Neumann, D. reviewed the muscular actions of the muscle in the hip through several discussions associated with the muscular kinesiology; including, muscle torque potential, moment arm, cross-sectional area, overall fiber direction and line of force about an axis of rotation. Extensive data was highlighted by literature reviewed by Dostal et al.; however, the data only represents one male cadaver specimen in the anatomic position. In the discussion, the line of force along with muscle torque was discussed in three cardinal planes of motion of the hip: sagittal, horizontal and frontal. Each plane of motion, the muscle’s actions were based on the orientation of its line of force about the joint’s axis of rotation. Muscle line of force was represented by a straight line between the attachment points. Therefore, muscle action was described as
the line of force potential direction of rotation of the joint, while muscle torque describes the strength of the action. The primary muscles of interest discussed in this review will be the gluteus maximus and gluteus medius. The primary actions of the gluteus maximus are hip extension, and external rotation while the gluteus medius is hip abduction. The secondary action of the gluteus medius is hip extension (middle and posterior fibers), external rotation (posterior fibers) and internal rotation (anterior fibers).11

As a hip extensor, the gluteus maximus and adductor magnus have the greatest cross-sectional area of all the primary extensors. As the hip is flexed to 60°, the moment arm increases allowing the gluteus maximus to produce higher torque. This extensor torque allows for rapid accelerating of the body upward and forward; such as pushing off into a sprint, arising from a deep squat or climbing a very steep hill. As a strong external rotator, the gluteus maximus is the largest muscle in the hip, accounting for about 16% of the total cross-sectional area of all hip musculature. Most notably at hip angles lower than 45° to 60° of flexion. Examining the line of force is directly about 45° in the frontal plane that allows for maximal-effort activation would be used to generate an external rotation force. For example in an abrupt change in direction while running (planting and cutting), the gluteus maximus’s line of force would generate a very powerful extension and external rotation torque to provide the necessary thrust to the combined cutting and propulsion action.11

The gluteus medius is the largest hip abductor, accounting for about 60% of the total abductor muscle cross-sectional. The broad, fan-shaped gluteus medius is subdivided into three sets of fiber; anterior, middle and posterior. All the fibers
contribute to hip abduction from the anatomic position; however, the anterior fibers also produce internal rotation and the posterior fiber produce extension and external rotation. In the frontal plane, a contraction of the hip abductor muscles can produce a femoral-on-pelvis hip abduction. For example, when stability is needed during single-limb support during walking. As the hip is flexed from 0° to 90°, the line of force changes, in the anterior fibers of the gluteus medius, from external rotation to internal rotation.11

Delp et al. investigated the rotation lever arms of the gluteus maximus, gluteus medius, gluteus minimus, iliopsoas, piriformis, quadratus femoris, obturator internus and obturator externus with hip flexion12. Four hemipelvic specimens were dissected with each muscle being identified, isolated and dissected with the origin and insertion areas marked. Each dissected specimen was mounted to a custom designed testing apparatus with a pulley system. A pulley was used to represent to correspond with the muscle origin. Six pulleys were used to represent the origin of the gluteus maximus, four pulleys for the gluteus medius and three pulleys for the gluteus minimus. Single pulleys were used for the remaining muscles. Changes in muscle length were measured at hip flexion angles of 0°, 20°, 45°, 60° and 90°. Lever arms were calculated by computing the derivative of the muscle length and rotation angle curve.12

In the gluteus medius, the anterior compartment has a small internal rotation lever arm, while the other compartments have external rotation lever arm. As the hip flexed, the internal lever arm increased while the other compartments switched from external rotation to internal rotation. In the gluteus maximus, at 0° of hip flexion, all the compartments of the gluteus maximus has an external rotation moment arm. As the hip is flexed, the first two anterior compartment switch from an external rotation to internal
rotation lever arms. The other compartments remain external rotators throughout the range of hip flexion; however, reduced rotational lever arms.\textsuperscript{12}

**Hip Strength and Injury Risk**

Cichanowski et al. investigated hip strength difference between collegiate female athletes diagnosed with patellofemoral pain with their unaffected leg and uninjured sport-matched controls\textsuperscript{7}. Thirteen collegiate female athletes (19.3±1.1 years) who were diagnosed with patellofemoral pain participated in the study. The control group was composed of thirteen female athletes with no previous history of patellofemoral pain. Hip strength consisted of performing a maximal isometric contraction for each of the six muscle group of the hip joint. The six muscle groups were tested were hip flexion, extension, abduction, adduction, internal and external rotation. All six muscle groups were tested in succession on the first trial with a three-to-five minute rest and then completion of the second trial. Muscle testing was performed as a make test with the peak muscle force being recorded and normalized to body weight. For hip extension, participants were tested in a prone position with the knee fully extended. For hip abduction, participants were tested in a side-lying position with the hip in a neutral position and knee fully extended. For external rotation, participants were seated with both the hip and knee flexed at 90 degrees.

Cichanowski et al. reported there was no statistical difference between age, body weight or years of hip school and college sports participation between the participants and control groups. A statistical difference was reported within the patellofemoral pain group when comparing injured leg and non-injured leg by the hip abductor muscle group ($p=0.003$) and by the hip external rotator muscle group ($p=0.049$). When comparing the
injured leg of the patellofemoral pain group and randomly selected leg of the control group, the injured leg of the patellofemoral pain group demonstrated a significantly globally weaker hip strength compared to the controls besides hip adductors. 

Fredericson et al. examined the hip abductor strength in long-distance runners with iliotibial band syndrome and comparing their injured leg strength to their noninjured leg and to the healthy legs of a control group. Twenty-four collegiate and club long-distance runners (14 males and 10 females) who were initially evaluated and diagnosed with iliotibial band syndrome participated in the research study. The mean age was for a female was 27.6±3.66 and for the male was 27.07±4.0. The control group composed of 30 distance runners from the Stanford University country and track teams from the 1995-1996 season. Hip abductor strength was measured by two examiners using a handheld dynamometer. Participants were placed in a side-lying position with the bottom leg flexed and the top leg in alignment with the rest of the trunk. Participants were instructed to push against the HHD at 30° with no encouragement given. Five trials were performed for each leg with 15-seconds rest between each trial. Also, all injured runners were enrolled in a 6-week rehabilitation program with sessions scheduled once a week.

Fredericson et al. reported before rehabilitation, participants with iliotibial band syndrome generated a hip abductor torque of 7.82±1.93 were significantly different from their uninjured leg (9.82+/−2.98) and the control group (10.19±1.10). Post rehabilitation, the injured group demonstrated an increase in average hip abductor torque to 10.55%, a 34.9% increase.
Ireland et al. examined the hip strength in females with and without patellofemoral pain\textsuperscript{8}. Fifteen females with patellofemoral pain (15.7±2.7 years) were recruited in this study with fifteen age-matched female controls (15.7±2.7 years). Participants underwent isometric muscle strength testing for hip abduction and external rotation using a handheld dynamometer with straps. For hip abduction, participants were positioned side-lying with the tested leg abduced about 10°. A strap was placed just proximal to the iliac crest and secured around the table. The HHD was placed just proximal to the lateral knee joint line and secured with a strap. For hip external rotation, participants were seated with the hip and knees flexed to 90°. A strap was used to stabilize the thigh of the tested leg. The HHD was placed just proximal to the lateral malleolus of the tested leg and secured with a strap. Participants performed one practice trial followed by three experimental trials with 15-seconds rest between trials. The peak values were normalized to body weight and used for analysis.\textsuperscript{8}

Ireland et al. reported participants with patellofemoral pain syndrome demonstrated significantly lower isometric strength values than their age-matched control group for both hip abduction (p<0.001) and external rotation (p<0.001).

Hewett et al. collected lower extremity biomechanical data in female athletes during the execution of sports movements and followed them prospectively to determine those who suffered noncontact ACL injury. Two hundred and five female adolescent soccer, basketball and volleyball players who were prospectively screened via three dimensional biomechanical analyses before their seasons. Nine anterior cruciate ligament injuries occurred in the 205 screened female athletes with seven occurring during soccer and two during basketball. The ACL injured group was similar in age.
compared to the uninjured (15.8 ± 1.0 vs. 16.1 ± 1.7 years, \(p=0.63\)). Prospectively, every female athlete performed a series of drop vertical jump trials. Participant started on top of a box (31-cm in height) with her feet positioned 35-cm apart. Female athletes were instructed to drop directly off the box and immediately perform a maximum vertical jump, raising both arms as if they were jumping for a basketball rebound. Three successful trials were performed with the first contact of the ground was used for analyses.\(^8\)

Hewett et al. reported that increased valgus motion and valgus moments at the knee joints during the impact phase of the drop vertical jump are key predictors of an increased potential for ACL injury in females\(^9\). Knee abduction angles were significantly different between the injured and non-injured group both at initial contact and at maximum displacement. A significant correlation between knee abduction angle and peak vertical ground reaction force were observed in the injured group (\(r=0.67, p<0.001\)) but not the non-injured group. The injured group demonstrated a greater stance phase peak external knee abduction moment (-45.3±28.5 Nm), compared to that of the uninjured group (-18.4±15.6 Nm) (\(p<0.001\)). Significant correlations existed between knee abduction moment and angle and peak ground reaction force (\(r=0.74\) and \(r=0.67\), respectively, \(p<0.05\)) in injured ACL group. A logistic regression analysis demonstrated that knee abduction moments and angles (initial contact and peak) were significant predictors of ACL injury status (\(p<0.001\)).\(^9\)

Pappas et al. identified the prevalence and overlap of the most common biomechanical deficit profiles associated with anterior cruciate ligament injury in adolescent female athletes during an unanticipated cutting task\(^10\). Four unique theories
have been developed for the explanation of anterior cruciate ligament injury risk. The ligament dominance theory suggests that female athletes at high risk perform athletic maneuvers with excessive knee valgus, hip adduction and internal rotation. The trunk dominance theory suggests that poor trunk control during athletic maneuvers leads to increase risk of anterior cruciate ligament injury. The quadriceps dominance theory suggest that excessive relative quadriceps forces or reduced hamstring recruitment places the anterior cruciate ligament at high risk for injury. The leg dominance theory suggests that large leg to leg asymmetries predispose athletes to injury. Seven hundred and twenty-one female (13.8±2.2 years) athletes that participated in basketball, volleyball and soccer were part of the study. Before the start of the season, each participant performed a sidestep cutting maneuver (45° cut) with kinematic and kinetic data recorded. Through a series of analyses, Pappas et al. used the following biomechanical deficit variables in the final model: knee valgus range of motion, peak knee valgus moment, trunk side flexion range of motion, hip and knee flexion range of motion and side-to-side difference in hip flexion range of motion.10

Pappas et al. reported the four latent profiles. The low risk profile had lower knee valgus range of motion, lower peak knee valgus moment, lower trunk side flexion range of motion, and lower side to side differences in hip range of motion whereas there was no difference for hip and knee flexion range of motion. The second most prevalent profile (24%) demonstrated a combination of high quadriceps and leg dominance deficits and was labeled quadriceps-leg (QL). The third most prevalent profile (22%) demonstrated a combination of trunk and leg dominance deficits and, to a lesser extent, ligament dominance deficits and was labeled trunk-leg-ligament (TLL). The fourth
profile (14%) demonstrated very high ligament dominance deficits only and was labeled ligament dominance (LD).¹⁰

**Novel Weight-Bearing Hip Strength Assessment**

*Standing Squat*

Lee et al. described a weight-bearing assessment to measure the muscular performance of the hip abductor and external rotator and compare the weight-bearing assessment with a traditional non-weight-bearing assessment.²² Twenty healthy volunteers (age=30.3±4.4 years) participated in the study composed of performing both weight-bearing and non-weight-bearing hip strength assessments while recording electromyography data for the superior gluteus maximus, medius and tensor fascia latae. In the two data collection sessions, the participants were tested using both methods in the first visit and only the weight-bearing method with EMG data collected on the second session. The weight-bearing method consists of the participant performing a mini squat positioned in 50° of knee flexion and 30° of hip flexion with their feet parallel to each other, shoulder width apart and arms folded across their chest. A force transducer and strap was secured just proximal to the femoral lateral epicondyle to measure hip abductor and external rotator muscular strength. For the gluteus medius, the electrodes were placed midway along the line between the iliac crest and the greater trochanter. For the superior gluteus maximus, the electrodes were placed 3 to 6-cm inferior from the posterior superior iliac spine, aligned toward the greater trochanter and following the gluteus maximus muscle fiber orientation. For the tensor fascia latae, the electrodes were placed 2 to 4-cm distal to the anterior superior iliac spine, following the fiber directions. The non-weight-bearing assessment consists of the
participant performing an isometric side-lying hip abduction with the tested hip superiorly and in a neutral position (0° of hip flexion, abduction and rotation). The axis of the motor-driven dynamometer was aligned with the hip joint center and the resistance pad positioned just proximal to the femoral lateral epicondyle. In both assessments, the participants perform three maximum isometric contractions for a 5-second period with verbal encouragement and force feedback provided.²²

For the weight-bearing assessment, the mean muscular activations for the superior gluteus maximus, medius and tensor fascia latae were 93.6%±30.8%, 77.0%±42.3%, and 37.5%±19.8% maximum voluntary isometric contraction, respectively. The assessment demonstrated an excellent test-retest reliability compared with the first session (2.8±0.6 N/kg) to the second session (2.8±0.6 N/kg) of force measurement. The normalized force measurements of the weight-bearing assessment (2.8±0.6 N/kg, range, 2.1-4.2 N/kg) and non-weight-bearing assessment (2.9±0.6 N/kg, range, 2.1-4.3 N/kg) were similar and was found to be significantly correlated (r= 0.75, p<0.01).²²

Lunge

Riemann et al. explored the sagittal plane kinematics and hip extensors kinetics between forward and lateral lunges.²⁶ Thirty-two participants between the ages of 18 to 40 years (16 females and 16 males) participated in the study. Participants performed forward and lateral lunges at a standardized distance and self-selected distance on the dominant leg. For the standardized forward lunge, participants were instructed to stride forward with the dominant leg so that the tested leg was parallel with the floor with their hands on their iliac crest. For the standardized lateral lunge, participants were
instructed to stride to the side with the dominant leg then flexing the stride leg until the knee flexed to $90^\circ$ with their hands on their iliac crest. The step length was standardized to 60% of their height. For the self-selected lunges, participants were instructed to perform the lunge at a step length that is comfortable and measured. Each participant performed six trials for each of the four conditions while kinematic and kinetic data was recorded.\textsuperscript{26}

Riemann et al. reported the standardized step length for the forward and lateral lunge was greater than the self-selected step length. The vertical total body center mass was significantly greater during the forward compared to the lateral lunge. In addition, the vertical total body center of mass was greater during the standardized step length lunge compared to the self-selected step length. A significant distance by direction interaction ($p<0.001$) was revealed and post hoc analysis revealed that for both the self-selected ($p<0.001$, $d=0.99$) and standardized ($p<0.001$, $d=1.8$) step distance. In addition the forward lunges self-selected step length lunge had significantly greater hip net joint moment impulse than the standardized step length lunge ($p<0.001$, $d=0.77$).\textsuperscript{26}

**Traditional Non-Weight-Bearing Hip Strength Assessment**

**Hip External Rotation Assessment**

Willcox et al. examined the effects of pelvis position and hip angle on the muscular activation of the gluteus medius, gluteus maximus and tensor fascia latae during a clam exercise\textsuperscript{37}. Ten males (25+/−5) and seven females (23+/−4) composed the seventy active participants of the study. Electromyography data was collected by placing surface electromyography electrodes over the gluteus medius, gluteus maximus
and tensor fascia latae. The electrode placement for the gluteus medius was one-third of the distance from the greater trochanter and the iliac crest. The electrode placement for the gluteus maximus was one-third of the distance from the second sacral vertebra and the greater trochanter. The electrode placement for the tensor fascia latae was 75-mm anterior to the anterior superior iliac spine, along a line oriented 30° anterior to the line joining the anterior superior iliac spine and the greater trochanter. Before performing the clam exercise, maximum voluntary isometric contractions (MVIC) was collected for normalization. Monoaxial electro-goniometer was used to monitor the position angle of the knee, hip, and spine. A pressure biofeedback unit was used to ensure stability and monitor impairments in the lumbopelvic stability. All testing was performed on the dominant leg as defined as the leg used to kick a ball. Participants completed the clam exercise in three hip angle variations (0°, 30°, and 60°) with the pelvis in neutral and repeated with the pelvis reclined to 35°. All variations were performed in a random order during the same session. Ten repetitions of 6-seconds were performed for each condition with a 3-minute rest between each condition. The clam exercise was performed with the participants in the side-lying position with the spine in neutral and knees flexed to 90°. The top knee (dominant) was abducted as far as possible while keeping the heels together and the lumbopelvic neutral. A bar was positioned to each participant’s maximal knee height which provided feedback to standardize each repetition. Each repetition was performed to the beat of a metronome over a 3-second period to raise then a 3-second period to lower the knee.37

Willcox et al. found that in gluteus maximus activation, no significance was found for hip angle-by-pelvis position interaction or main effect for the hip angle; however, a
significant main effect for pelvis position. Across all average hip angles, performing clam exercise in the neutral pelvis position resulted in a greater gluteus maximus activation compared to the reclined position (17.8% versus 10.1% MVIC). In gluteus medius activation, no significant difference was found for hip angle-by-pelvis position interaction; however, main effects for pelvis position and hip angles were significant. Across all average hip angles, performing clam exercise in the neutral pelvis position resulted in a greater gluteus medius activation compared to the reclined position (20.2% versus 14.1% MVIC). When averaged across pelvis positions, gluteus medius activation was greater at 60° hip flexion compared to 0° hip flexion (19.8% versus 14.6% MVIC). For the tensor fascia latae, there was no significant hip angle-by-pelvis position interaction or main effect for hip angle or pelvis position.  

Selkowitz et al. evaluated common rehabilitation exercises that targeted the gluteal muscles while minimizing activation of the tensor fascia latae using a fine-wire electromyography (EMG) assessment. Twenty volunteers (10 males and 10 females) between the ages of 18 to 50 years old (27.9+/−6.2 years) were recruited for the study. Fine-wire electrodes were inserted in the superior gluteus maximus, gluteus medius and tensor fascia latae to evaluate muscular activation while performing eleven gluteal specific exercises. For the superior gluteus maximus, the fine-wire was inserted superior and lateral to the midpoint of a line drawn between the posterior superior iliac spine and the posterior greater trochanter. For the gluteus medius, the fine-wire was inserted 2.5 cm distal to the midpoint of the iliac crest (middle compartment of the gluteus medius). For the tensor fascia latae, the fine-wire was inserted distal and slightly lateral to the anterior superior iliac spine and medial and superior to the greater
trochanter. The normalization of the EMG signal for each muscle was performed during a maximum voluntary isometric contraction (MVIC) for 5-seconds with the highest EMG signal amplitude being used. All eleven exercises were performed using a metronome set at 40-beats per minute with the concentric and eccentric phases comprised of 1-metronome beat. Five repetitions of each exercise were performed with 2-minute rest between each exercise. The following exercises were performed in random order: hip abduction in side-lying, clam with elastic resistance around thighs, bilateral bridge, unilateral bridge, hip extension in quadruped on elbows with knee extending, hip extension in quadruped on elbows with knee flexed, forward lunge with erect trunk, squat, sidestep with elastic resistance around thighs in a squatted position, hip hike and forward step-up. In this review, forward lunge, hip abduction in side-lying, clam with elastic resistance around thighs were the exercise of primary focus. For the forward lunge, participants started with the knees and hips at 0° in the sagittal and frontal plane. Participants were instructed to step forward with the tested leg until both legs reached 90° of knee and hip flexion. For hip abduction in side-lying, participants laid on their side opposite of their dominant leg. The treatment table was positioned along a wall. The non-dominant (non-tested) leg was flexed to 45° at the hip and 90° at the knee with the lower back and plantar foot positioned against the wall. The dominant leg was fully extended. Participants were instructed to abduct the tested hip to about 30° and return the leg to the table. For the side-lying clam with elastic resistance around thighs, each participant laid on the side opposite of their dominant leg. Both legs were flexed to 45° at the hip and 90° at the knee with the dominant (tested) leg on top. With the participant’s back and plantar foot placed against the wall, the participants were
instructed to raise the dominant knee up off the other knee until the hip was in 30° of abduction then return to the starting position while keeping both heels in contact. A blue-colored Thera-Band tubing was around the distal thighs with no stretch or slack on the tubing before the movement.27

Selkowitz et al. found the following exercises were statistically significant in a 1-way repeated-measures ANOVAs: side-lying abduction, clam with elastic band, bilateral bridge, hip hike, hip extensions in quadruped on elbows with knee extending, hip extension in quadruped on elbows with the knee flexed, sidestep with elastic band, squat and unilateral bridge. For the side-lying hip abduction, normalized mean EMG amplitudes for each muscle were the following: superior gluteus maximus, 23.7+/−15.3 MVIC (p=0.033); gluteus medius, 43.5+/−14.7 MVIC (p=0.012); and tensor fascia latae, 32.3+/−13.1 MVIC. A contrast test revealed the normalized EMG amplitude for the gluteus medius was significantly greater than the tensor fascia latae; however, the superior gluteus maximus was significantly less than the tensor fascia latae. For clam with elastic band, normalized mean EMG amplitudes for each muscle were the following: superior gluteus maximus, 26.7+/−18.0 MVIC (P=0.006); gluteus medius, 43.6+/−26.1 MVIC (P<0.001); and tensor fascia latae, 11.4+/−11.4 MVIC. The contrast test revealed the normalized EMG amplitude for both the gluteus medius and superior gluteus maximus was significantly higher than the TFL.27

Sidorkewicz et al. examined the relationship of the muscular activation levels of the gluteus medius and tensor fascia latae during side-lying hip abduction and clamshell38. Thirteen healthy males (24.8+/−4.2 years) volunteered to participate in the research study. Surface electromyography electrodes were placed over the middle
fibers of the gluteus medius and tensor fascia latae. The side-lying hip abduction was performed with different hip rotation orientation from internal, external and neutral while clamshell was performed in three different hip flexion angles, 30°, 45°, and 60°. After practice trials were completed, participants performed three consecutive trials of each exercise with each variation. The order of the exercise was randomized. For side-lying hip abduction, participants were instructed to lie on their left side with their legs together, knee extended and left arm supporting their head. Hip orientation was changed by either pointing their toes towards the floor (internal rotation), forward (neutral), or toward the ceiling (external rotation) as much as possible, without rotating their pelvis forward or backward. Participants were instructed to lift their right leg toward the ceiling as high as possible while maintaining the hip rotation orientation throughout the entire movement. For side-lying hip clamshell, participants were in the same position as the side-lying hip abduction. Before each trial, hip flexion angle would be changed to 30°, 45° or 60° and then adjust their knee angle so that the heels of the participant’s feet were in line with their lower back. Participants were instructed to keep their feet together as they externally rotate their right hip as much as possible without rotating their pelvis backward.38

Sidorkewicz et al reported that during the side-lying clamshell, the mean gluteus medius-to-tensor fascia latae EMG signal amplitude ratio did not vary a significant amount. For clamshell at 30° hip flexion, gluteus medius-to-TFL ratio were 26.80±24.08% MVIC and 7.96±6.13% MVIC; clamshell at 45° hip flexion, 35.55±34.25% MVIC and 8.16±5.17% MVIC; and clamshell at 60°, 36.49±33.06% MVIC and 7.04±4.56% MVIC. Similar results were found with the side-lying hip abduction in
different hip rotation orientation. For hip abduction with internal rotation, gluteus medius-to-tensor fascia latae ratio were 36.70±14.55% MVIC and 36.20±17.51% MVIC; in neutral, 48.67±20.21% MVIC and 49.69±25.11% MVIC; and with external rotation, 36.50±16.46% MVIC and 40.21±30.72% MVIC.\textsuperscript{38}

**Hip Extension Assessment**

Worrell et al. investigated the influence of hip joint position on electromyography and torque generation of the hamstrings and gluteus maximus\textsuperscript{28}. Twenty-five males and females participated in the study. Prior to the testing, surface electrodes were placed on the skin overlying the gluteus maximus and hamstrings. For the gluteus maximus, the participants performed a gluteal contraction at 0° of hip flexion and the largest palatable muscle mass was the site for the electrodes. For the hamstrings, the participants performed knee flexion at 60° with the largest area of muscle mass being the site for the electrodes. For knee flexion testing, participants were positioned prone on the testing table with the hips at 0°. A strain gauge was positioned perpendicular to the tibia and secured to the testing table while the participants performed isometric knee flexion at 0°, 30°, 60° and 90° of knee flexion. For hip extension testing, participants were prone on the testing table with the hips at 0°. The strain gauge was positioned perpendicular to the femur while the participants performed isometric hip flexion at 0°, 30°, 60° and 90° of hip flexion and actively maintaining the knee in 90° of knee flexion.\textsuperscript{28}

Worrell et al. reported a trial-to-trial reliability for the torque data to range from 0.81 to 0.99 and for the electromyography data to range from 0.92 to 0.99. For the knee flexion testing, significant angle-depend difference (\(p<0.05\)) was revealed in both hamstring electromyography and torque production. Post hoc testing reported mean
knee flexor torque was significantly greater at 30° than at any other angle and
significantly less at 90° than all other angles. Hamstring electromyography activity was
greatest during the 30° to 60° angles, both of which produced significantly more
hamstring electromyography activity. The gluteus maximus demonstrated greater
electromyography activity at 30° to 60° than at 90°. For the hip extension testing, a
significant angle-dependent difference was reported in both torque and
electromyography data. The greatest hip extension torque was at 90° of hip flexion.
The greatest mean electromyography activity for the gluteus maximus occurred at 0° of
hip flexion and the least at 90° of hip flexion.²⁸

Lue et al. examined the influence of testing position on the reliability of hip
extensor strength²⁴. Intrasession reliability was determined from all 47 participants (24
females and 23 males). Interrater reliability aspect of the study was composed of 16
participants. Hip strength was quantified by a calibrated Micro FET2 handheld
dynamometer in a break test. To compare the effects of positions on reliability of hip
extensor measurement, hip extension was tested in two positions, the prone position
and prone-standing position. For the prone position, participants were prone on a
height-adjustable table. The tested leg was hyperextended at 20° and the knee in full
extension. For the prone-standing position, participants stood and leaned forward
against the height-adjustable table. The hip was flexed at 45° and the knee in full
extension on the tested leg, the non-tested leg was in a comfortable and stable position.
The intrasession reliability was evaluated by one examiner using three trials for the two
positions. Each trial lasted about 3-seconds with 5-seconds rest between each trial. A
1-minuate rest was taken between each position. The intrarater reliability was tested in the same way in a 1-week time span by another examiner.\textsuperscript{24}

Lue et al. reported no significant difference between the strength of the right and leg. The ICC\textsubscript{1,3} in the intrasession reliability for both prone position (0.92) and prone- standing (0.94) position reported having an excellent reliability. The ICC\textsubscript{2,3} in the intrarater reliability for the prone- standing position (0.92) were greater than that for the prone position (0.65). Only prone standing position demonstrated an excellent intrarater reliability.\textsuperscript{24}

Suehiro et al. investigated the influence of hip joint position on the muscular activation of the gluteus maximus, hamstrings, erector spinae and multifidus during a prone hip extension with knee flexion\textsuperscript{30}. Twenty-one healthy males (mean age=20.2±0.4 years) volunteered to have surface electrodes applied to the right gluteus maximus, right hamstring, and bilateral multifidus to measure muscle activities during a prone hip extension. For the right gluteus maximus, the electrodes were placed halfway between the greater trochanter and the second sacral vertebra. For the right hamstring, the electrodes were placed approximately halfway between the gluteal fold and the popliteal fold. For bilateral erector spinae, the electrodes were placed at the level of L1, 2-3 cm external to the spinous process. For bilateral multifidus, the electrodes were placed at the level of L5/S1 immediately lateral to the spinous process. Participants performed a prone hip extension with knee flexion with the hip joint in three positions: 1) neutral of 0° hip abduction and external rotation, 2) abduction of 15° hip abduction, and 0° hip external rotation, 3) abduction with external rotation of 15° hip abduction with 20° external rotation. A line formed by the thigh center line and a line perpendicular to a line
connecting both posterior superior iliac spines was used to determine hip joint’s abduction angle. Hip external rotation angle was formed by the lower leg center line and a plumb line passing through the patella. Participants were instructed to extend their right hip joint until the patella was raised 5-cm above the table and maintained for 5-seconds. Each participant performed the exercise three times in each randomized hip position with 2-minute rest period between each position.\textsuperscript{30}

Suehiro et al. reported the intra-rater reliability of the muscle activities of each of the three hip joint positions were excellent with an ICC (1,3) of 0.91-0.98. The hip joint position of abduction with external rotation produced the highest gluteus maximus muscle activity (41±23.6%) and gluteus maximus/hamstring ratio (4.9±4.4%). The hamstring, right lumbar erector spinae and left lumbar multifidus demonstrated the lowest EMG activity levels in the abduction with external rotation position (respectively 7.2±10.4%, 13.8±12.5%, and 22.4±9.8%).\textsuperscript{30}

Kang et al. examined the activation of the gluteus maximus and hamstring during a prone hip extension with knee flexion in three hip abduction positions\textsuperscript{29}. Eighteen males and twelve females volunteered to have surface electrodes placed on the dominant leg of the gluteus maximus and hamstring during a prone hip extension with knee flexion movement. For the gluteus maximus, the surface electrode was placed in the middle of the muscle at an oblique angle that was halfway between the greater trochanter and second sacral vertebra. For the hamstring, the electrode was placed parallel to the muscle about halfway between the gluteal fold and popliteal fold. Relative onset was calculated by taking the difference between the gluteus maximus onset and hamstring onset. Participants laid prone with their knee bent at 90 on a table
with their feet shoulder width apart and arms at their sides. Two boards were used as a
guideline for hip abduction at the 0°, 15° and 30° with its center point placed under the
participant’s anterior superior iliac spine. Participants were instructed to lift their knee
toward the ceiling until the patella was lifted 5-cm off the table and then asked to
maintain the extended position for 5-seconds. Each participant performed the exercise
three times for each hip abduction position with 30-second rest period each trial.29

Kang et al reported that the electromyography data during the exercise were
significantly different among the three hip abduction position. For gluteus maximus
amplitude, 30° hip abduction position demonstrated the greatest electromyography data
(29±11% MVIC). For hamstring amplitude, 0° hip abduction position demonstrated the
greatest electromyography data (17±15% MVIC). There was a significant difference in
electromyography data onset among the three hip abduction position. At the 15° and
30° hip abduction position, the relative onset difference was negative (-0.02±0.11 ms
and -0.21±0.20 ms respectively) implicating that the gluteus maximus fired earlier than
the hamstring.29

**Hip Abduction Assessment**

Widler et al. conducted a validity and reliability research study investigating the
assessment of hip abductor muscle strength in three different body positions25. Sixteen
healthy participants, eight males and eight females, (mean age=31±6) were recruited to
perform a hip abductor muscle strength assessment in three positions while collecting
bilateral gluteus medius EMG data. To investigate the test-retest reliability of the hip
abductor muscle strength assessment, two identical test sessions were completed. Hip
abductor muscle strength assessment was performed side-lying, standing and supine in
a random order. Participants were given a standardized instruction followed by a series of familiarization trials per side in each of the three different body positions. A custom frame was used to stabilize the handheld dynamometer. For the side-lying position, participants laid on their side with the non-test leg at 30° hip and knee flexion. The test leg was abducted to 10° before contacting the stabilized HHD. For supine position, participants laid on their back with the test leg at 10° of hip abduction. For the standing position, participants stood next to the treatment table with the contralateral hip in contact against the wall for body stabilization. The tested leg was abducted to 10° before contacting the stabilized HHD. During all of the test positions, the tested leg was fully extended with the HHD located 5-cm proximal to the lateral femoral condyle. The participants were instructed to produce a maximal voluntary contraction for about 4-seconds. Bilateral electromyography data was collected for the gluteus medius with electrodes positioned in the direction of the line from the crista iliaca to the trochanter.

Widler reported a significant main effect of position for hip abductor strength was observed by the research authors. The maximal voluntary contraction strength in the side-lying position was 30% greater than that in the supine position (p<0.001) and 10% greater than that in the standing position (p<0.05). For EMG activity, a main body effect of body position was observed. The contralateral-to-tested electromyography activity in the side-lying position was significantly lower than both the supine and standing ratio. Intra-class correlation coefficients were high to moderate for side-lying (0.902), supine (0.826) and standing (0.880).

Otten et al. examined the surface electromyography activation levels of the subdivision of the gluteus medius in different strength testing positions. Twenty
physically active male participants (mean age = 37±5 years) volunteered to participate in this study. Surface electromyography was placed bilaterally on the subdivision of the gluteus medius. For the anterior portion of the gluteus medius, the electrode location was 50% of the distance between the anterosuperior iliac spine and the greater trochanter. For the middle portion, the electrodes were placed 50% of the distance between the greater trochanter and iliac crest. For the posterior portion, the electrodes were positioned a third of the distance between the posterior ilium and the greater trochanter. Surface EMG data was collected in eight different strength testing positions. Supine with straight legs. Supine with the contralateral leg flexed so the medial malleolus is at the same height as the joint line of the knee of the tested leg. Side-lying with the hip joint in neutral. Side-lying with the tested leg in 20° of abduction. Side-lying with the hip of the tested leg maximally internally rotated. Side-lying with the hip of the tested leg maximally externally rotated. Side-lying with the tested leg in full extension and external rotation. Side-lying in the clam position with the hip flexed to 45° and knee flexed to 90°. Participants were instructed to perform three maximal voluntary isometric contractions with the dominant leg with a handheld dynamometer. A 10-seconds rest period was given between each trial and 2-minute rest period between each test position. All the testing was performed by one examiner, who had three years of clinical experience. The three electromyography activation levels of each gluteus medius subdivision were averaged then normalized by the highest electromyography activation level for that given subdivision. 39

Otten et al. found the anterior portion of the gluteus medius demonstrated a relatively high activation level (>75%) for five out of eight positions. For the middle and
posterior position of the gluteus medius, only two positions, SL0 and SLIR, demonstrated similar activation levels. The activation levels on the contralateral gluteus medius, the anterior portion showed significant differences in all testing positions. For the middle portion, only four out of eight positions, SL0, SL20, SLIR and SLclam showed significant differences. For the posterior position, only five out of eight positions, SSL, SL0, SL20, SLIR and SLclam, demonstrated the same. An overall position effect was revealed for each gluteus medius subdivision. For the contralateral leg, there was an overall position effect for the anterior and middle portion of the gluteus medius. An overall interaction effect between position and side was shown for each gluteus medius subdivision.39

**Relationship between Hip Strength and Knee Kinematics**

Sigward et al. investigated the associated between frontal plane knee excursion and clinical measures of hip strength, ankle and hip range of motion during a drop landing task in female soccer athletes18. Thirty-nine female soccer athletes (15.5±1.0 years) participated in the study with all measurements obtained on the dominant limb. Isometric force production of the hip extensor, abductor and external rotator was quantified using a handheld dynamometer. For hip extension, participants stood in a standing prone position with the hip flexed to 45 and knee flexed to 90. The HHD was positioned 5-cm proximal to the popliteal crease. For hip abduction, participants were in a side-lying position with the tested limb abducted 20 and extended 5. The HHD was position over the lateral femoral condyle. For hip external rotation, participated were seated with the hip in neutral rotation and knee flexed to 90. The HHD was positioned over the distal, medial tibia. A strap was positioned over the HHD to avoid any effects
of variable force application by the examiner. Passive hip internal and external range of
motion was measured with a standard goniometer along with ankle dorsiflexion. Three-
dimensional trajectory data was captured using a 6-camera motion analysis system as
the participants performed a drop landing task off a 46-cm platform. Four trials were
collected as participant were instructed to step off a 46-cm platform, leading with their
dominant limb, landing on boot feet and performing a maximal vertical jump.18

Sigward et al. reported a wide range of strength and range of motion values. Of
the six clinical evaluated, only two were found to be predictors of frontal plane knee
excursion during a drop landing task. Hip external rotation and ankle dorsiflexion range
of motion explained 27% of the variance in frontal plane knee excursion. These
independent variables significantly correlated with the amount of frontal plane knee
excursion. In a stepwise regression, hip external rotation range of motion was the
largest predictor, explaining 16.3% of the overall variance. While ankle dorsiflexion
range of motion explained 10.8% of the total variance. The hip strength measurements
had no correlation and was no significant.18

In a similar study, Bandholm et al. examined the relationship between hip
abduction and external rotation strength and frontal plane knee control during a drop
landing task in recreational female athletes20. Thirty-three recreational females
(22.4±2.5 years) participated in the study. Isometric hip abduction and external rotation
strength was quantified using a HHD on the dominant limb. For hip abduction,
participants were in a supine position and hip in neutral position. For hip external
rotation, participants were seated with both hip and knee in 90 of flexion. The highest
strength value was used and expressed as the maximal voluntary torque per kilo body
mass. During the drop landing task, three-dimensional data was obtained by 8-camera motion analysis system. Participants were instructed to drop landing task by jumping off a 45-cm platform then upon landing perform a maximal vertical jump. The calculated mean of the five drop landing trials were used in analysis and reported as absolute and relative changes in knee marker distance. 

Bandholm et al. reported on average hip abduction (1.81±0.23 N m/kg) were 270% stronger than external rotation (0.49±0.07 N m/kg) and were significantly inter-correlated (r=0.43, p=0.012). During the drop landing task, participants had an average absolute change in knee marker distance of 5.1±2.4cm, from 41.2±3.0 cm at foot to ground contact to 36.1±4.2 cm at the time of minimal knee marker distance during the contact phase of the drop landing task. For relative change in knee marker distance, the average was 0.03±0.01 cm/cm body height, from 0.25±0.02 cm/cm body height at foot to ground contact to 0.22±0.03 cm/cm body height at the time of minimal knee marker distance during the contact phase of the drop landing task. Maximal hip abduction torque did not correlate with absolute or relative change in knee marker distance; however, external rotation torque correlated with greater absolute (r=0.48, p=0.005) and relative (r=0.43, p=0.012).

Hollman et al investigated the relationship between frontal-plane knee alignment, hip alignment, hip muscle strength and hip muscle EMG recruitment during a single-leg step down in healthy females. Twenty females (age=24.0±2.6) were recruited to perform a single leg step down in addition to assessing hip strength concentrically with a HHD. Single leg step down was performed on the dominant foot with frontal plane projection angle being measured by using a three-dimensional motion capture system.
Participants were instructed to maintain a single leg stance for two seconds on a 15-cm step then perform the step down over two-seconds, gently making floor contact with the heel of the contralateral foot and ascend to the starting position. Hip strength measurement was obtained with a HHD in a standard manual muscle testing for hip abduction and external rotation. For hip abduction, participants were in a side-lying position with the tested leg abducted 30°. The HHD was positioned just proximal to the greater trochanter of the femur. For hip external rotation, the participants were seated with the hip and knee in flexion and femur externally rotated 30°. The HHD was position just proximal to the medial malleolus. Participants were instructed to exert maximum isometric force against the HHD during a 5-seconds period. Examiners recorded peak force for data analysis.¹

Hollman et al. reported an increase in hip adduction (95% CI of the change=6.9-11.3, t=8.76, p<0.001) and knee valgus (95% CI of change=-2.0 to 4.3, t=0.76, p=0.45) during the single leg step down. Gluteus maximus and medius EMG recruitment was 9.2% and 21.9% MVIC increase compared with the single leg stance, respectively. Knee valgus and hip adduction positively correlated (r=0.75, p<0.001) during the single leg step down. Gluteus maximus negatively correlated with knee valgus (r=-0.45, p=0.026). Hip abduction strength positively correlated (r=0.46, p=0.022) with knee valgus.¹

Thijs et al. investigated the relationship between hip strength and frontal plane excursion of the knee during a forward lunge¹⁹. Eighty-four officer cadets (8 females and 76 males) were recruited to perform a forward lunge and assess hip strength for the following muscle groups: hip flexion, extension, abduction, adduction, internal and
external rotation. Participants were instructed to perform a series of three forward lunges of their dominant foot with a limited knee flexion angle of 45°. Hip muscle strength was measured with a HHD as participants in a make test. For hip flexion, participants were in seated position and the HHD positioned just proximal to the knee. For hip extension, participants were prone with the HHD positioned just proximal to the popliteal crease. For hip abduction, participants were supine with the hip of the tested leg abducted and in neutral position with the knee extended. For hip adduction, participants were supine with the untested leg in full abduction and test leg in adduction and knees fully extended. For internal and external rotation, the participants were in a seated position with the HHD just proximal to the respected lateral and medial malleolus. Isometric muscle contraction against the HHD was held for five-seconds of the dominant leg for three practice trials and three test trials. Peak force production from the three trial test was used for data analysis.\textsuperscript{19}

Thijs et al. reported no significant difference in muscle strength for any of the six tested muscle groups between the valgus and varus groups. In the valgus group, no significant correlations was force between the force ratios of the hip muscles, flexion/extension ($r=-0.08$, $p=0.40$), abduction/adduction ($r=-0.15$, $p=0.12$), and external/internal rotation ($r=0.14$, $p=0.15$) and the valgus movement at the knee. In the varus group, a significant positively correlation was reported between external/internal rotation force ratio and the amount of knee varus during the forward lunge movement ($r=0.31$, $p=0.03$).\textsuperscript{19}

Jacobs and Mattacola investigated the relationship between hip abductor strength and knee kinematics during a landing task in males and females\textsuperscript{40}. Eighteen
healthy recreationally adults (10 females and 8 males) were recruited for the study. Participants were instructed to perform a single leg forward hop with their dominant leg over a rectangular wooden obstacle (length 61 cm, height 10 cm, width 10 cm). Participants starting position was about 45% of their height away from an “x” marked on the floor, then were instructed to hop over the obstacle and land on the “x” with the same leg that initiated the hop while maintaining balance in the landing for about 5-seconds. Participants performed 7 hopping trials (3 practice trials, 4 test trials) with biomechanical data collected for peak joint angle, knee flexion, knee valgus and knee external rotation. Eccentric hip strength data was collected using a Biodex System 3 Isokinetic dynamometer at a preset velocity of 120°/s. Strength data was collected for hip abductor strength in the standing position. Average peak torque was collected from 5 test trials and used for analysis.  

Jacobs and Mattacola reported no significant difference between males and females for average peak torque or any of the peak joint angles. The average peak torque for males were 1.41±0.25 N · m/kg and for females were 1.45±0.35 N · m/kg. For males, there were no significant correlations between average peak torque and any of the peak joint angles. There was a significant negative correlation (r=-0.61, p=0.03) between peak knee valgus angle and eccentric hip abduction strength in females during a forward hop task.

Claiborne et al. examined the relationship between peak torque in hip strength and frontal plane knee movement in a single leg squat. Fifteen males and fifteen females were recruited in the study to perform a single leg squat and to assess their hip strength with the Biodex Isokinetic Dynamometer. Single leg squat was performed from
a standing position to about 60° of knee flexion. Participants were instructed to perform five to seven nonconsecutive single leg squats to obtain three acceptable trials for data analysis. Hip strength measurement was performed with a Biodex Isokinetic for hip abduction, adduction, flexion, extension, internal and external rotation, knee flexion and extension at a preset angular velocity of 60°/s. Peak torque was determined for each muscle group and contraction mode. The order of strength testing for all participants was concentric/concentric followed by eccentric/eccentric abduction/adduction, flexion/extension, internal/external rotation and knee flexion/extension. Each participant performed three maximal effort repetitions for each muscle group and contraction mode and used for data analysis. Claiborne et al. reported that during the single-leg squat, peak flexion angle for males and females was 62.45±9.56 and 65.89±7.79, respectively. Peak knee valgus angle for females was 3.67±4.58 and for males was 2.75±5.27. Males generated significantly greater absolute peak torque than females for all strength measurements beside eccentric internal rotation. When normalized to body mass, males generated significantly greater peak torque than females for concentric hip adduction, flexion, knee flexion, knee extension and eccentric hip extension. For frontal-plane movement, linear regression analysis revealed that concentric abduction, knee flexion and knee extension peak torque were significant predictors during a single-leg squat. A Pearson-Product Moment coefficient demonstrated a weak to moderate, but significant negative relationship between concentric hip abduction (r=-0.365, p<0.05), concentric knee extension (r=-0.369, p<0.05) and concentric knee flexion (r=-0.426, p<0.001) strength and frontal-plane knee movement during a single leg squat.
Willson et al. investigated the influences of the muscles of the trunk, hip and knee on the orientations of the lower extremity during weight-bearing activities\textsuperscript{4}. Forty-six collegiate basketball, soccer and volleyball athletes (22 females and 24 males) participated in a study that consist of a two-dimensional analysis of a single leg squat and lower extremity strength assessment. Single leg squat was performed by every participant for analysis of the frontal-plane projection angle of the knee. Frontal plane projection angle was assessed by taking the imaginary straight line from anterior superior iliac spine to midpoint of the tibiofemoral joint and midpoint of the tibiofemoral joint to midpoint of the ankle mortise. To obtain this single leg squat, participants stood in front of an adjustable stool that represented the distance in which the participant would need to achieve $45^\circ$ of knee flexion. Core and hip strength measurements were calculated for peak isometric torque. A handheld dynamometer stabilized with a strap was utilized for the following muscle groups: trunk extension, trunk flexion, trunk lateral flexion, hip abduction, hip external rotation, knee flexion and knee extension. Participants perform two practice trials and three test trials on the dominant leg for five-second of maximum isometric force. Three trials were used for analysis.\textsuperscript{4}

Willson et al. reported that the mixed-factor ANOVA revealed a significant gender x position interaction (F (1,42) =5.05, \( p=0.03 \)) for the frontal-plane projection angle during the single-leg squat. A follow-up paired t-test for frontal-plane projection angle indicated that females typically moved toward more extreme movements during the single-leg squat compared to males. The relationship between hip external rotation strength and frontal plane projection angle was statistically significant ($r=0.40$, \( p=0.004 \)).
Hip abduction strength had no significant correlation with frontal plane projection angle ($r=0.23$, $p=0.07$).

Baldon et al. examined the relationship among eccentric hip abductor and external rotator torque and lower extremity kinematics between genders during a single-leg squat. The study consists of sixteen males (21.8±2.8) and sixteen females (20.5±1.7) to perform a single leg squat and evaluated for eccentric hip strength using an Isokinetic dynamometer. Participants performed a single-leg squat with their dominant leg to about 75° of knee flexion and return to the starting position. The participants were instructed to perform the single-leg squat at a standardized time of 2.0±0.3s. Eccentric hip abductor and external rotator torque was evaluated at a preset angular velocity of 30° per second. Hip abductor torque was tested with the participant in a side-lying position with the dominant leg positioned parallel to the ground in neutral hip flexion/extension and medial/lateral rotation. Hip external rotator torque was tested with the participant seated with their knees and hip flexed at 90 and with the test leg placed at 10 of internal rotation. Participants performed two series of five maximal repetitions with three-minute rest period between the series. Peak torque was collected and normalized to body mass for analysis.

Baldon et al. reported females display a greater knee abduction, femur adduction and contralateral pelvic depression excursions during the single-leg squat compared to males. The hip strength normalized to body mass were greater in males compared to females. A significant relationship was found between eccentric hip abductor ($r=0.61$, $p=0.01$) torque and frontal plane movement in females. A significant correlation for both
genders between eccentric hip abductor \((r=0.49, \ p=0.004)\) and lateral rotator \((r=0.36, \ p=0.04)\) torque and frontal plane movement in the knee.\textsuperscript{13}

Lawrence et al. investigated the relationship between the biomechanics of a single-leg drop landing and hip external rotation strength\textsuperscript{14}. Seventy-two recreational active participants were a part of the study. Initially, the participants were ranked and split into groups based on their right external rotation strength data. The top 22\% were denoted as the strong group and the lower 22\% were denoted the weak group. For hip external rotational strength, participants were in a seated position with the hip and knee flexed to 90 degrees. The HHD was positioned just proximal to the medial malleolus with a strap. A stabilizing strap was used over the mid-thigh. Three trials were averaged and normalized to body mass. The strong and weak group were asked back to perform eight single-leg drop landing trials. Participants were instructed stand on a 40-cm stable handing bar then land onto a force platform on their dominant foot. Following the single-leg drop landing trials, quadriceps and hamstring isokinetic strength testing was performed using an isokinetic dynamometer. In addition, isometric hip abduction was assessed with a HHD to determine if the results were due to total lower extremity weakness or isolated hip external rotator weakness. All strength data were normalized to body mass.\textsuperscript{14}

Lawrence et al. reported a significant difference in isometric hip external rotation strength \((p<0.001)\), isometric hip abduction \((p<0.001)\) and isokinetic knee flexion \((p=0.001)\). There was a significant different in vertical group reaction force \((p=0.001)\) between the groups. At the knee, the strong group had a significant lower external knee adduction moment \((p=0.001)\) and a different external knee flexion moment \((p=0.021)\).
At the hip, the strong group produced a lower external hip adduction moment ($p=0.003$). A Spearman rho between hip external rotation strength and vertical group reaction force was $r=-0.468$ ($r^2=0.22$, $p=0.005$), net anterior shear force at the knee $r=-0.448$ ($r^2=0.20$, $p=0.008$), and external knee valgus moment $r=-0.471$ ($r^2=0.22$, $p=0.005$).

Boudreau et al. examined the hip activation levels in a lunge, single-leg squat and step-up-and-over exercise$^{21}$. Forty-four healthy individuals participated in the research study. Electromyographic activation levels were measured for both gluteus medius, dominant rectus femoris, adductor longus and gluteus maximus. Participants performed three functional exercises on the dominant side while recording electromyographic activation levels. For the lunge, participants stood feet shoulder width apart and forward lunge their leg length on the dominant side. For the single-leg squat, participants were instructed to perform a single-leg squat on the dominant side as far down as possible. For the step-up-and-over, participants stood feet aligned behind a box and step over the box with the dominant leg followed by the non-dominant leg.$^{21}$

There was a main effect of exercise for the rectus femoris with greater activation levels during the single-leg squat than the lunge and step-up-and-over and for the lunge when compared with the step-up-and-over. A main effect was found for the gluteus maximus and dominant gluteus medius during the single-leg squat than step-up-and-over and lunge. A main effect for the non-dominant gluteus medius revealed a greater activation level during the lunge than the single leg squat.$^{21}$

Heinert et al. investigated the relationship between hip abductor strength and lower extremity kinematics during running$^{17}$. One hundred and ten female recreational
athletes were recruited to participate in the study that composed of hip abductor strength testing and treadmill running. A handheld dynamometer fixed on top of an anchoring station measured the dominant leg during the hip abductor strength testing. Participants were in a side-lying position with the dynamometer positioned about 5-cm proximal to the knee joint line with the hip abducted about 20°. The hips were in a neutral rotation position and the thigh, leg and feet parallel to the table. Five trials were performed for 5-seconds with a 10-second rest between each trial. The mean of the five trials were obtained and represented as a percentage of each participant’s body mass. The strength values were divided into quartiles and the fifteen participants that exhibited the greatest strength and the fifteen that exhibited the least strength returned for a second data collection where a kinematic assessment of their running pattern was performed. Each participants were given a pair of shoes to wear on the treadmill with cameras positioned at 60° intervals around the treadmill. Participants ran a speed between 1.80 to 3.20 m/s for seven 3-second trials to be collected.¹⁷

Heinert et al. reported a significant demographic different between the strong hip abductor and weak hip abductor group in the mean body mass (p=0.009). The weak hip abductor group demonstrated a weight about 10-kg more than the strong hip abductor group. No significant difference was found in knee flexion angle (p=0.827), hip flexion angle (p=0.977), hip abduction angle (p=0.133) or pelvic tilt (p=0.55) between the weak and strong hip abductor group during the stance phase of running. A significant difference was found in knee abduction angle between the weak and strong hip abductor groups at all portions of the stance phase during running ((p=0.008). The
weak group demonstrated about $4^\circ$ greater knee abduction than the strong hip abductor group.$^{17}$

Malloy et al. examined the influence of hip muscles strength on lower extremity biomechanics during an unanticipated single-leg landing task$^{15}$. Twenty-three female soccer athletes were recruited in the study. Maximal isometric hip strength was tested for the hip abductor and external rotator muscle groups using a handheld dynamometer. For the hip abductor muscle group, participants were tested in a side-lying position with the tested hip position in $0^\circ$ of rotation and the bottom leg slightly flexed for stability with a pillow placed between the legs. The handheld dynamometer was placed 1-inch proximal to the lateral epicondyle and secured to the leg using a custom foam cutout and canvas strap. For the hip external rotator muscle group, participants were tested in a seated position with the hip placed in neutral frontal and transverse rotation. The dynamometer was placed 1-inch proximal to the medial malleolus and secured to the leg using a custom foam pad and canvas strap that was attached to an athletic table. Participants were instructed to press upwards with maximal effort over a 5-second perform. Maximal hip abductor and external rotator isometric torque was calculated and then subsequently normalized to the participant’s body mass. Each participant was required to perform three different types of unanticipated single-leg landing tasks that consist of: single-leg land and hold, single-leg and side cut, and single-leg land and forward run. Three to five successful trials was performed while 14-cameras recorded kinematic data and a force plated collected kinetic data. Box height was normalized for each participant maximal vertical jump. All single-leg land task required each
participant to jump off the box and land on the force plate and stabilize their body during the landing without touching the opposite foot to the ground.\textsuperscript{15}

Malloy et al. performed a multivariate analysis of variance to determine if mean difference exist on the dependent variables among the three unanticipated task. The results demonstrated no significant different between the tasks for any of the dependent variables ($F=1.095$, $p=0.376$) and therefore the mean values of the kinematic and kinetic variables of each three tasks were combined for final analysis. Significant correlation was found between hip external rotator strength and transverse plane joint moments at the hip and knee. Specifically, hip external rotator strength significantly correlated with the peak hip external rotation moment and peak knee internal rotator moment. Frontal plane hip excursion and transverse plane knee excursion were also significantly correlated with hip external rotator strength.\textsuperscript{15}

McCurdy et al. investigated the relationship between selective lower extremity strength measurements and movement of the hip and knee during a bilateral and unilateral landing task\textsuperscript{16}. The study recruited females (20.9±1.62 years) with two to ten years of athletic background. Participants came in the laboratory for three testing sessions consisting of a multi-joint strength tests, single-joint strength tests and drop jump tests each performed with 48 hours of rest. The multi-joint strength tests consist of a bilateral back squat and a modified single leg squat. A three-repetition maximum assessment took place to predict the one-repetition maximum. Isometric hip external rotation, extension, and abduction comprised of the single-joint strength test with a handheld dynamometer secured to the participant with a stabilizing strap around the laboratory table. Concentric and eccentric knee flexion and extension strength values
were assessed using an Isokinetic Dynamometer (Biodex Medical System). Participants were instructed to perform a bilateral and unilateral drop jump tasks. The box height for the bilateral jumps was 60-centimeters and 30-centimeters for the unilateral jumps.\textsuperscript{16}

McCurdy et al. found knee valgus and hip adduction to significantly correlated with the back squat (knee valgus=-0.77, hip adduction=-0.50), modified single leg squat (knee valgus=-0.81, hip adduction=-0.54), isometric hip external rotation (knee valgus=-0.61), isometric hip abduction (knee valgus=-0.42), isometric knee extension (knee valgus=-0.49, hip adduction=-0.45) and isometric knee flexion (knee valgus=-0.51, hip adduction=-0.68) in the bilateral jump measures. Knee valgus and unilateral hip adduction revealed a strong correlation with the back squat (knee valgus=-0.83, hip adduction=-0.65), modified single leg squat (knee valgus=-0.78, hip adduction=-0.57) isometric hip external rotation (knee valgus=-0.58), and isometric knee flexion (knee valgus=-0.41, hip adduction=-0.49). A partial, first-order correlations was calculated comparing the relationship between knee valgus and hip adduction with the other strength measures during a bilateral and unilateral jump. Isometric knee flexion remained significant to hip adduction (-0.57) and isometric hip abduction strength remained significant to knee valgus (-0.43) during a bilateral jump. Only isometric hip external rotation strength remained significant to knee valgus (-0.41) during an unilateral jump.\textsuperscript{16}

**Handheld Dynamometer**

Schmidt et al. investigated the reliability of the make test and break test for hip abduction assessment in healthy individuals\textsuperscript{23}. Thirty-nine participants (22 females and
17 males) volunteered to be part of the research study. For the testing procedures, each participant was randomly assigned to the make test or break test using a handheld dynamometer (HHD) on the first appointment. The participants were positioned side-lying with an external belt secured around the anterior superior iliac crest and treatment table to stabilize the pelvis. Each examiner performed the manual muscle test to ensure the participant met all inclusion criteria. Three examiners were involved in the research study with two examiners randomly assigned to each participant to perform the hip strength assessments at each appointment. The make test or break test was conducted by the first examiner on both hips. Participants were allowed 2 minutes of rest between each test. On the second appointment, the second examiner performed whichever test that was not performed on the first appointment, make test or break test, twice on each hip.23

Schmidt et al. reported on mean hip strength that was subdivided into three classification; test type, gender and leg dominance. Overall, the break test demonstrated higher variability values than the make test. Subdivided by gender, male variability values were consistently higher. Patterns for variability was not as clear when further subdivided by leg dominance. Reliability values for the break test was 0.908 and for the make test was 0.916. In a separate analysis for each gender result in small reliability values for the break test (males, 0.875 and females, 0.889) while reliability values for the make test decreased for the females only (male, 0.910 and females, 0.804).23

Stratford et al. investigated the reliability of make and break tests using a handheld dynamometer (HHD) and isokinetic dynamometer (Kin-Com)31. Thirty-two
healthy females (27.9±5.8 years) participated in the study. A single examiner tested the participant’s right elbow in four testing conditions: Kin-Com make and break test and HHD make and break test. Participants were position supine and the right elbow flexed to 90° and fully supinated. Resistance for both device was provided 1-cm proximal to the wrist joint. For the make test, participants were instructed to pull as hard as you can and for the break test, participants were instructed to pull as hard as you can: now don’t let me move your arm. Two maximal trials were performed for each four test conditions over a five second period.\textsuperscript{31}

Stratford et al. reported the reliability coefficient for the make and break test obtained from the Kin-Com device. The ICC (2,1) reported a 0.89 (95% CI, 0.79-0.95) for the make test and 0.89 (95% CI, 0.78-0.94) for the break test from the Kin-Com device. For the HHD, the make test reported a 0.95 (95% CI, 0.89-0.97) and the break test reported a 0.87 (95% CI, 0.75-0.93). A repeated measures analysis of variance reported a statistically significant difference between the make and break tests and between trials. For the HHD, the break test was 1.06 times greater than the make test and for the Kin-Com, the break test was 1.03 times greater than the make test.\textsuperscript{31}

Krause et al. investigated the influences of lever arm and stabilization on the reliability and torque productions for hip abduction and adduction muscle testing.\textsuperscript{41} Twenty-one healthy participants (nine females and twelve males) were part of the study. Six different testing positions were performed and each test was administered three times on each participant. Hip abduction and adduction was tested in a short and long lever arm in addition with hip abduction and adduction using a fixed stabilization, a bench. For the short lever arm, the HHD was placed 7-cm above the lateral joint line of
the knee and for the long lever arm, the HHD was placed 5-cm above the lateral malleolus. A break test was used with the maximal force being normalized to weight and height for analyses.  

Krause et al. reported the values of the intrarater reliability for the various test to ranged from 0.80 to 0.93 and the interrater reliability ranged from 0.62 to 0.82. The maximal hip abduction torque tested in the long-lever position (mean, 10.7%±2.2% body weight X height) was significantly greater (p<0.001) than torque produced in the short-lever position (mean, 7.1%±1.5% body weight X height). The difference in torque production capability between bench stabilization and manual stabilization in the long-lever position was statistically significant (p=0.001).

Krause et al. investigated the effects of examiner strength of hip strength testing using a handheld dynamometer. Thirty adults (24±1.4 years) were recruited to participate in the study. Three examiner of different strength performed manual muscle tests in two different positions for hip extension, abduction and external rotation. Examiner strength was quantified by a one repetition maximum leg press and chest press. A short and long-lever was used to assess hip abduction and extension. Hip external rotation was assessed seated and prone. A make test was performed for all manual muscle tests. Participants were instructed to increase their force over a 5-second time interval for two maximal contractions for each manual muscle test.

Krause et al. reported that all muscle tests were reliable with intrarater reliability (ICC 3,1) ranged from 0.82 to 0.97 and interrater reliability (ICC 2,1) ranged from 0.81 to 0.98. For hip abduction, a short-lever torque value were significantly greater than a
long-lever value ($p<0.001$). For hip external rotation, the seated position was significantly greater than the prone position ($p<0.001$).
References


electromyographic and torque generation during maximal voluntary isometric 
contractions of the hamstrings and gluteus maximus muscles. *The Journal of 

29. Kang SY, Jeon HS, Kwon O, Cynn HS, Choi B. Activation of the gluteus 
maximus and hamstring muscles during prone hip extension with knee flexion in 

Muscle Activity during Prone Hip Extension with Knee Flexion. *Journal of 

31. Stratford PW, Balsor BE. A comparison of make and break tests using a hand-
held dynamometer and the Kin-Com. *The Journal of Orthopaedic and Sports 


34. Gottschalk F, Kourosh S, Leveau B. The functional anatomy of tensor fasciae 

Anatomy and biomechanics of gluteus maximus and the thoracolumbar fascia at 


42. Krause DA, Neuger MD, Lambert KA, Johnson AE, DeVinny HA, Hollman JH.

APPENDIX A

UNIVERSITY OF HAWAI’I INSTITUTIONAL REVIEW BOARD APPROVAL LETTER

UNIVERSITY OF HAWAI’I INSTITUTIONAL REVIEW BOARD MODIFICATION APPROVAL LETTER
TO: Freemyer, Bret, PhD, ATC, University of Hawaii at Manoa, Kinesiology and Rehabilitation Science
FROM: Lin-deshetter, Denise, Dir, Hum Stds Prtg, Biomedical IRB
PROTOCOL TITLE: EXAMINING THE RELATIONSHIP BETWEEN HIP STRENGTH MEASURES TO KNEE INJURY RISK FACTORS
FUNDING SOURCE: NONE
PROTOCOL NUMBER: 2016-30257
APPROVAL PERIOD: Approval Date: September 30, 2016 Expiration Date: July 17, 2017

NOTICE OF APPROVAL FOR HUMAN RESEARCH

Your application for the Human Studies Program approval of a proposed change for the study was approved by the Human Studies Program on September 30, 2016 by the University of Hawaii Institutional Review Board (UH IRB). This application qualified for Expedited Review under CFR 46.110 and 21 CFR 56.110, Category 4, 7b. Note that this approval date is for the proposed revision, and does not reset the annual study expiration date. Please refer back to your most recent IRB approval letter (initial application or continuing review) for the study's expiration date. Regulations require that continuing review be conducted on or before the one-year anniversary date of IRB approval.

If future revisions to your study are required, please seek the Human Studies Program approval prior to their implementation. If a change is necessary to protect the safety or welfare of study participants, it is permissible to make the change without prior approval. However, you must notify the Human Studies Program as soon as possible, requesting approval for the change.

The UH IRB approval for this project will expire on July 17, 2017. If you expect your project to continue beyond this date, you must submit an application for renewal of this Human Studies Program approval. The Human Studies Program approval must be maintained for the entire term of your project.

If future revisions to your study are required, please seek the Human Studies Program approval prior to their implementation. If a change is necessary to protect the safety or welfare of study participants, it is permissible to make the change without prior approval. However, you must notify the Human Studies Program as soon as possible, requesting approval for the change.

You are required to maintain complete records pertaining to the use of humans as participants in your research. This includes all information or materials conveyed to and received from participants as well as signed consent forms, data, analyses, and results. These records must be maintained for at least three years following project completion or termination, and they are subject to inspection and review by the Human Studies Program and other authorized agencies.

Please notify this office when your project is complete. Upon notification, we will close our files pertaining to your project. Reactivation of the Human Studies Program approval will require a new Human Studies Program application.

Please contact this office if you have any questions or require assistance. We appreciate your cooperation, and wish you success with your research.

Notes:

Modifications:
TO: Freemeyer, Bret, PhD, ATC, University of Hawaii at Manoa, Kinesiology and Rehabilitation Science
Urbi, Anthony-Edward, BS, ATC
FROM: Lin-deshelter, Denise, Dir, Hum Stds Prog, Biomedical IRB
PROTOCOL TITLE: EXAMINING THE RELATIONSHIP BETWEEN HIP STRENGTH MEASURES TO KNEE INJURY RISK FACTORS
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Please contact this office if you have any questions or require assistance. We appreciate your cooperation, and wish you success with your research.

Notes:
Modifications:
APPENDIX B

CONSENT FORM FOR PARTICIPATION

ASSENT FORM FOR PARTICIPATION

PARENTAL/LEGAL GUARDIAN CONSENT FORM FOR PARTICIPATION
UNIVERSITY OF HAWAI‘I

CONSENT FORM FOR PARTICIPATION IN A RESEARCH STUDY

Study Title: EXAMINING THE RELATIONSHIP BETWEEN HIP STRENGTH MEASURES TO KNEE INJURY RISK FACTORS

Principal Investigator: Bret Freemyer, PhD, ATC
1337 Lower Campus Road
Honolulu, Hawaii 96822
United States
(808) 956-7606

Sponsor: University of Hawaii, Manoa; Department of Kinesiology and Rehabilitation Science

Site: University of Hawaii, Manoa
PE/A Complex Room 100
1337 Lower Campus Road
Honolulu, Hawaii 96822
United States

Summary

In this consent form, “you” always refers to the participant. This consent form may contain words that you do not understand. Please ask the research investigators to explain any words or information that you do not clearly understand.

You are being asked to be in a research study. The purpose of this consent form is to help you decide if you want to be in the research study. Please read this consent form carefully. To be in a research study you must give your informed consent. “Informed consent” includes:

- Reading this consent form
- Having the research investigators explain the research study to you, and
- Asking questions about anything that is not clear

You should not join this research study until all of your questions are answered. Things to know before deciding to take part in a research study:

- The main goal of a research study is to learn things to help female athletes in the future.
- No one can promise that a research study will help you.
- Taking part in a research study is entirely voluntary. No one can make you take part.
- If you decide to take part, you can change your mind later on and withdraw from the research study.

After reading and discussing the information in this consent form you should know:

- Why this research study is being done;
- What will happen during the research;
• Any possible benefits to you;
• The possible risks to you;
• How problems will be treated during the study and after the study is over.

If you take part in this research study and upon request, you will be given a copy of this signed and dated consent form.

**Purpose of the Study**

The purpose of this research study is to examine how hip strength affects the risk of knee injuries in female athletes.

**Procedures**

If you decide to take part in this research study, the data collection session will take approximately 60 minutes. At the data collection session, you will be asked to:

1. Complete the Physical Activity Readiness Questionnaire (PAR-Q) about your physical ability to perform the instructed task.
2. Push as hard as you can into a strength measuring device in 6 different motions. This include three while laying down on a table and three while standing up. Each will be done three times on each leg.
3. Drop down and forward off a 30 centimeter box and jump as high as possible upon landing. This will be done 3 to 5 times.
4. Jog 4 meters then side-cut like you were playing in a sport like basketball. This will be done 3 to 5 times.

**Risks and Discomforts**

Due to the level of physical activity involved, there is a risk of injury. You may have some discomfort, muscle cramping or soreness during or after the test session. Although we have a fall prevention system, there is a small chance of falling during the side-cutting and drop vertical jump task. There is a very remote chance of cardiac arrest and/or death. These risks are comparable to your routine activities of daily living.

You cannot participate in this research study if you are pregnant because the side-cutting and drop vertical jump collected may not accurately represent your normal characteristics. If you are unaware that you are pregnant, participation in this research study will result in no more danger to the mother or fetus than normal activities of daily living. However, if you become pregnant or think you might be pregnant during the course of this research study, you must inform the research investigators, and you will be taken out of the study.

**Benefits**

You will not receive direct/immediate benefits from participating in this research study. However, you will obtain information regarding your hip muscular strength and dynamic movement capacity.

**Costs**
You will be responsible for parking and transportation to and from the University of Hawaii, Manoa, Kinesiology and Rehabilitation Science, Human Performance and Gait Laboratory (Sherriff 100). All equipment and testing procedures will be of no cost to you.

Confidentiality:

All research information about you will be held confidential to the extent allowed by state and federal law. Your personal information will not be given to anyone without your written permission. A code, which will be known only to research investigators, will be used instead of your name on any records pertaining to this study. Research records which may be identifiable to you will be kept in a secure locked file in the Department of Kinesiology and Rehabilitation Science at the University of Hawaii at Manoa when not being used. These materials will be permanently disposed of (destroyed) upon completion of the research study.

This consent covers all information about you that is used or collected for this research study; however, your name and other identifying information will not be used or revealed. However, agencies with research oversight, such as The University of Hawaii Committee on Human Studies, have the right to review research records.

Some of the persons or groups that receive your study information may not be required to comply with federal privacy regulations, and your information may lose its federal privacy protection and your information may be disclosed without your permission.

Compensation in Case of Injury:
No financial compensation or coverage will be routinely provided by the research investigators. If you require treatment for any injury or illness related to procedures required by the research study, or if you suffer side effects while in the research study, you should contact your primary care doctor. The cost of this medical care and advice will be billed to you or your medical insurance in the usual manner. By signing this consent form, you will not give up any legal rights.

Voluntary Participation and Withdrawal
Your participation in this research study is voluntary. You may decide not to participate or you may leave the research study at any time. Your decision will not result in any penalty or loss of benefits to which you are entitled.
Your participation in this research study may be stopped at any time by the research investigators without your consent for any of the following reasons:

- it is in your best interest;
- or for any other reason.

Questions
Contact Dr. Bret Freemyer at freemyer@hawaii.edu or 808-956-7606 for any of the following reasons:

- if you have any questions about this study or your part in it
- if you feel you have had a research-related injury or
• if you have questions, concerns or complaints about the research

If you have questions about your rights as a research participant or if you have questions, concerns or complaints about the research, you may contact:

Human Studies Program
University of Hawaii at Manoa
1960 East-West Road
Biomedical Building B-104
Honolulu, HI 96822
Telephone: (808) 956-5007
E-mail: uhirb@hawaii.edu

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Human Studies Program will not be able to answer some study-specific questions; such as questions about appointment times. However, you may contact Human Studies Program if the research team cannot be reached or if you wish to talk to someone other than the research team.

Do not sign this consent form unless you have had a chance to ask questions and have gotten satisfactory answers. If you agree to be in this study, you will receive a signed and dated copy of this consent form for your records.
Statement of Consent

Study Title: EXAMINING THE RELATIONSHIP BETWEEN HIP STRENGTH MEASURES TO KNEE INJURY RISK FACTORS

I have read this consent form, or it has been read to me. All of my questions about the research study and my part in it have been answered. I consent to take part of this research study out of my own free will, and I understand that I may withdraw from participation at any time.

Participant Name (Print) __________________________        Date __________________________

Signature of Participant (18 years and older) __________________________        Date __________________________
UNIVERSITY OF HAWAI’I

ASSENT FORM FOR PARTICIPATION IN A RESEARCH STUDY

Study Title: EXAMINING THE RELATIONSHIP BETWEEN HIP STRENGTH MEASURES TO KNEE INJURY RISK FACTORS

Principal Investigator: Bret Freemyer, PhD, ATC
1337 Lower Campus Road
Honolulu, Hawaii 96822
United States
(808) 956-7606

Sponsor: University of Hawaii, Manoa; Department of Kinesiology and Rehabilitation Science

Site: University of Hawaii, Manoa
PE/A Complex Room 100
1337 Lower Campus Road
Honolulu, Hawaii 96822
United States

Summary

In this consent form, “you” always refers to the participant. This consent form may contain words that you do not understand. Please ask the research investigators to explain any words or information that you do not clearly understand.

You are being asked to be in a research study. The purpose of this consent form is to help you decide if you want to be in the research study. Please read this consent form carefully. To be in a research study you must give your informed consent. “Informed consent” includes:

- Reading this consent form
- Having the research investigators explain the research study to you, and
- Asking questions about anything that is not clear

You should not join this research study until all of your questions are answered. Things to know before deciding to take part in a research study:

- The main goal of a research study is to learn things to help female athletes in the future.
- No one can promise that a research study will help you.
- Taking part in a research study is entirely voluntary. No one can make you take part.
- If you decide to take part, you can change your mind later on and withdraw from the research study.

After reading and discussing the information in this consent form you should know:

- Why this research study is being done;
- What will happen during the research;
• Any possible benefits to you;
• The possible risks to you;
• How problems will be treated during the study and after the study is over.

If you take part in this research study and upon request, you will be given a copy of this signed and dated consent form.

**Purpose of the Study**

The purpose of this research study is to examine how hip strength affects the risk of knee injuries in female athletes.

**Procedures**

If you decide to take part in this research study, the data collection session will take approximately 60 minutes. At the data collection session, you will be asked to:

1. Complete the Physical Activity Readiness Questionnaire (PAR-Q) about your physical ability to perform the instructed task.
2. Push as hard as you can into a strength measuring device in 6 different motions. This include three while laying down on a table and three while standing up. Each will be done three times on each leg.
3. Drop down and forward off a 30 centimeter box and jump as high as possible upon landing. This will be done 3 to 5 times.
4. Jog 4 meters then side-cut like you were playing in a sport like basketball. This will be done 3 to 5 times at about 3.5 m/s for each leg.

**Risks and Discomforts**

Due to the level of physical activity involved, there is a risk of injury. You may have some discomfort, muscle cramping or soreness during or after the test session. Although we have a fall prevention system, there is a small chance of falling during the side-cutting and drop vertical jump task. There is a very remote chance of cardiac arrest and/or death. These risks are comparable to your routine activities of daily living.

You cannot participate in this research study if you are pregnant because the side-cutting and drop vertical jump biomechanics collected may not accurately represent your normal characteristics. If you are unaware that you are pregnant, participation in this research study will result in no more danger to the mother or fetus than normal activities of daily living. However, if you become pregnant or think you might be pregnant during the course of this research study, you must inform the research investigators, and you will be taken out of the study.
Benefits

You will not receive direct/immediate benefits from participating in this research study. However, you will obtain information regarding your hip muscular strength and dynamic movement capacity.

Costs

You will be responsible for parking and transportation to and from the University of Hawaii, Manoa, Kinesiology and Rehabilitation Science, Human Performance and Gait Laboratory (Sherrick 100). All equipment and testing procedures will be of no cost to you.

Confidentiality:

All research information about you will be held confidential to the extent allowed by state and federal law. Your personal information will not be given to anyone without your written permission. A code, which will be known only to research investigators, will be use instead of your name on any records pertaining to this study. Research records which may be identifiable to you will be kept in a secure locked file in the Department of Kinesiology and Rehabilitation Science at the University of Hawaii at Manoa when not being used. These materials will be permanently disposed of (destroyed) upon completion of the research study.

This consent covers all information about you that is used or collected for this research study; however, your name and other identifying information will not be used or revealed. However, agencies with research oversight, such as The University of Hawaii Human Studies Program, have the right to review research records.

Some of the persons or groups that receive your study information may not be required to comply with federal privacy regulations, and your information may lose its federal privacy protection and your information may be disclosed without your permission.

Compensation in Case of Injury:

No financial compensation or coverage will be routinely provided by the research investigators. If you require treatment for any injury or illness related to procedures required by the research study, or if you suffer side effects while in the research study, you should contact your primary care doctor. The cost of this medical care and advice will be billed to you or your medical insurance in the usual manner.

By signing this consent form, you will not give up any legal rights.

Voluntary Participation and Withdrawal

Your participation in this research study is voluntary. You may decide not to participate or you may leave the research study at any time. Your decision will not result in any penalty or loss of benefits to which you are entitled. Your participation in this research study may be stopped at any time by the research investigators without your consent for any of the following reasons:

- it is in your best interest;
- or for any other reason.

Questions
Contact Dr. Bret Freemyer at freemyer@hawaii.edu or 808-956-7606 for any of the following reasons:

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Statement of Consent

Study Title: EXAMINING THE RELATIONSHIP BETWEEN HIP STRENGTH MEASURES TO KNEE INJURY RISK FACTORS

I have read this consent form, or it has been read to me. All of my questions about the research study and my part in it have been answered. I consent to take part of this research study out of my own free will, and I understand that I may withdraw from participation at any time.

Participant Name (Print) __________________________ Date __________________________

Signature of Participant (under 18 years old) __________________________ Date __________________________
UNIVERSITY OF HAWAI‘I

PARENTAL / LEGAL GUARDIAN CONSENT FORM FOR PARTICIPATION IN A RESEARCH STUDY

Study Title: EXAMINING THE RELATIONSHIP BETWEEN HIP STRENGTH MEASURES TO KNEE INJURY RISK FACTORS

Principal Investigator: Bret Freemyer, PhD, ATC
1337 Lower Campus Road
Honolulu, Hawaii 96822
United States
(808) 956-7606

Sponsor: University of Hawaii, Manoa; Department of Kinesiology and Rehabilitation Science

Site: University of Hawaii, Manoa
PE/A Complex Room 100
1337 Lower Campus Road
Honolulu, Hawaii 96822
United States

Summary

In this consent form, “you” always refers to the participant. If you are a parent or guardian, please remember that “you” refers to the study participant. This consent form may contain words that you do not understand. Please ask the research investigators to explain any words or information that you do not clearly understand.

Your child is being asked to be in a research study. The purpose of this consent form is to help you decide if you want your child to be in the research study. Please read this consent form carefully. For your child to be in a research study you must give your informed consent. “Informed consent” includes:

- Reading this consent form
- Having the research investigators explain the research study to you, and
- Asking questions about anything that is not clear

You should not allow your child to join this research study until all of you and your child questions are answered. Things to know before allowing your child to decide to take part in a research study:
• The main goal of a research study is to learn things to help female athletes in the future.
• No one can promise that a research study will help your child.
• Allowing your child to take part in a research study is entirely voluntary. No one can make your child take part.
• If you or your child decide to take part, you or your child can change your mind later on and withdraw from the research study.

After reading and discussing the information in this consent form you and your child should know:

• Why this research study is being done;
• What will happen during the research;
• Any possible benefits to your child;
• The possible risks to your child;
• How problems will be treated during the study and after the study is over.

If your child takes part in this research study, you will be given a copy of this signed and dated consent form upon request.

**Purpose of the Study**

The purpose of this research study is to examine how hip strength affects the risk of knee injuries in female athletes.

**Procedures**

If you allow your child to take part in this research study, the data collection session will take approximately 60 minutes. At the data collection session, your child will be asked to:

1. Complete the Physical Activity Readiness Questionnaire (PAR-Q) about your physical ability to perform the instructed task.
2. Push as hard as you can into a strength measuring device in 6 different motions. This include three while laying down on a table and three while standing up. Each will be done three times on each leg.
3. Drop down and forward off a 30 centimeter box and jump as high as possible upon landing. This will be done 3 to 5 times.
4. Jog 4 meters then do a cutting motion like you were playing in a sport like basketball. This will be done 3 to 5 times.

**Risks and Discomforts**

Due to the level of physical activity involved, there is a risk of injury. Your child may have some discomfort, muscle cramping or soreness during or after the test session. Although we have a fall prevention system, there is a small chance of falling during the side-cutting and drop vertical jump task. There is a very remote chance of cardiac arrest and/or death. These risks are comparable to routine activities of daily living.

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activities of daily living. However, if your child becomes pregnant or think they may be pregnant during the course of this research study, you and your child must inform the research investigators, and they will be taken out of the study.

Benefits

You or your child will not receive direct/immediate benefits from participating in this study. However, your child will obtain information regarding their hip muscular strength and dynamic movement capacity.

Costs

You and your child will be responsible for parking and transportation to and from the University of Hawaii, Manoa, Kinesiology and Rehabilitation Science, Human Performance and Gait Laboratory (Sherriff 100). All equipment and testing procedures will be of no cost to you.

Confidentiality:

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Some of the persons or groups that receive your study information may not be required to comply with federal privacy regulations, and your information may lose its federal privacy protection and your child’s information may be disclosed without you or your child permission.

Compensation in Case of Injury:

No financial compensation or coverage will be routinely provided by the research investigators. If your child require treatment for any injury or illness related to procedures required by the research study, or if your child suffer side effects while in the study, you and your child should contact their primary care doctor. The cost of this medical care and advice will be billed to you or your medical insurance in the usual manner.

By signing this consent form, your child will not give up any legal rights.

Voluntary Participation and Withdrawal

Your child participation in this research study is voluntary. Your child may decide not to participate or decide to leave the research study at any time. Your child’s decision will not result in any penalty or loss of benefits to which your child may be entitled.
Your child participation in this research study may be stopped at any time by the research investigators without your consent for any of the following reasons:

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- or for any other reason.

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_______________________________________
Name of the Minor Participant’s Name (Print)

_______________________________________
Name of Parent/Guardian of Participant (Print)  Relationship to Participant

_______________________________________
Signature of Parent/Guardian of Participant  Date
APPENDIX C

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE (PAR-Q)

ANTHROPOMETRICS AND DATA COLLECTION FORMS
Name: ___________________  Subject ID#: _____________  Date: ________

Physical Activity Readiness Questionnaire (PAR-Q)
1. Has your doctor ever said that you have a heart condition and that you should only perform physical activity recommended by a doctor?

2. Do you feel pain in your chest when you perform physical activity?  
   Yes _____  No _____

3. In the past month, have you had chest pain when you were not performing any physical activity?  
   Yes _____  No _____

4. Do you lose your balance because of dizziness or do you ever lose consciousness?  
   Yes _____  No _____

5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?  
   Yes _____  No _____

6. Is your doctor currently prescribing any medication for your blood pressure or for a heart condition?  
   Yes _____  No _____

7. Do you know of any other reason why you should not engage in physical activity?  
   Yes _____  No _____

     Yes _____  No _____
Anthropometric Data

Subject ID#: ___________________  Date: ___________________
Age: _________________________  Dominant Leg:  L □   R □
Body mass: _____(lbs)  →  _____(kgs)  Height (mm): __________ 
50% Height (cm): ___________  60% Height (cm): __________

<table>
<thead>
<tr>
<th>Side-cutting maneuver trials</th>
<th>1.0 m/s — 1.33 m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial #</td>
<td>Which foot hit the force plate</td>
</tr>
<tr>
<td>1</td>
<td>R / L</td>
</tr>
<tr>
<td>2</td>
<td>R / L</td>
</tr>
<tr>
<td>3</td>
<td>R / L</td>
</tr>
<tr>
<td>4</td>
<td>R / L</td>
</tr>
<tr>
<td>5</td>
<td>R / L</td>
</tr>
<tr>
<td>6</td>
<td>R / L</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Drop vertical jump trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial #: Which foot hit the force plate</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Drop vertical jump trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial #: Which foot hit the force plate</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
</tbody>
</table>
# MMT Data Collection Sheet

**Subject ID#: __________________**

**Date: __________________**

## Closed-kinetic chain positions

<table>
<thead>
<tr>
<th></th>
<th>Right Leg</th>
<th>Left Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trial 1 Score (ft-lb(_f))</td>
<td>Trial 2 Score (ft-lb(_f))</td>
</tr>
<tr>
<td>Standing squat abduction bilateral (SABB)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standing squat adduction bilateral (SADB)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standing squat abduction unilateral (SABU)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lunge (LNG)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Open-kinetic chain positions

<table>
<thead>
<tr>
<th></th>
<th>Right Leg</th>
<th>Left Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trial 1 Score (ft-lb(_f))</td>
<td>Trial 2 Score (ft-lb(_f))</td>
</tr>
<tr>
<td>Hip external rotation (HER)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip extension (HEXT)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip abduction (HAB)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>