ABSTRACT

HIP BRACES AS A CONSERVATIVE TREATMENT ALTERNATIVES FOR PATIENTS WITH FEMOROACETABULAR IMPINGEMENT

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Femoroacetabular Impingement (FAI) in the hip is defined as the abnormal bone geometry in the proximal femur (ball) and/or the acetabulum rim (socket) that causes impingement of the soft tissue between the articulating bone. This bone abnormality often leads to pain in the hip, a reduced range of motion, and early-onset osteoarthritis. Since the FAI injury mechanism is mechanical in nature, treatment regiments must address the altered mechanics to be effective. A conservative treatment utilizing hip braces to address the injury mechanism was studied. Two hip braces, the SERF Brace and a modified Groin Brace, were tested under a slow walking, fast walking, and a slow jogging condition in healthy controls using motion capture. The data collected suggested both braces alter the hip motions in favor of addressing the injury mechanisms faced by FAI patients. Therefore, hip braces may be used as a conservative treatment to alter hip motions to decrease the injury-inducing mechanism associated with FAI.

APPROVED BY DIRECTOR OF HONORS THESIS

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Hip Braces as Conservative Treatment Alternatives for Patients with Femoroacetabular Impingement

A Thesis Submitted to the Faculty of

Baylor University

In Partial Fulfillment of the Requirement for the

Honors Program

By

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Waco, Texas

May 2016

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ACKNOWLEDGMENTS

This thesis would not have been possible without the help, encouragement, and guidance of many people along the way. First and foremost, I would like to thank my advisor, Dr. Jonathan H. Rylander, for his support and encouragement in every phase of this project. From taking on the burden of mentoring me and my thesis before ever even teaching a class here at Baylor to instilling within me the confidence to lead my own project as an undergraduate. I am forever grateful for the all the opportunities and advice he has given me since joining his lab and the patience he has showed in teaching me new concepts, improving my research skills, and in reviewing my writing.

I would also like to thank the many members of the Baylor BioMotion Lab. Carley and Larissa for being there since day one when we first started setting up the motion capture system and learned how to use it by testing it on one another. As well as JC Meyers for helping me collect and process data. Thank you to all of my fraternity brothers who helped in keeping me sane during the writing process. And a special thank you to my fraternity brothers and roommates who sacrificed their time to participate as subjects to complete this honors thesis. Thank you to the Baylor Undergraduate Research Scholarly Achievement Award (URSA) Grant for funding my study.

Lastly, but most certainly not least, thank you to my loving parents, Pravin and Arpita, and my brother, Shukan, for giving me the emotional support and encouragement to pursue the honors program at Baylor University and for allowing me to attend such a prestigious university.

CHAPTER ONE

Introduction

Femoroacetabular Impingement (FAI) is an abnormal bone morphology in the hip that has a pathomechanical injury mechanism. It effects primarily young, active individuals between the ages of 25-40 and has been show to lead to early onset hip osteoarthritis. The only known cure for the disease is arthroscopic surgery but many patients are not able to or prefer to put off surgery due to their daily activities or sports season. Therefore, a more enhance conservative treatment must be developed to help reduced the pain and range of motion FAI patients experience. However, in order to effectively address a conservative treatment for this disease, basic hip anatomy and mechanics should be understood first.

Hip Joint Anatomy

The hip joint is described as being a conforming ball and socket joint between the proximal femoral head (ball) and the acetabulum (socket). The acetabulum is the intersecting point of ilium, ishium, and pubis bones in the pelvis (Polkowski, 2010) and is anteverted at 15 -20º (Tonnis, 1999). The femoral neck is oriented at 120º relative to the long bone shaft that runs down the thigh in the coronal plane and has an average anteversion of 12-14º in the axial plane with respect to the distal femoral epicondylar axis (Hamill, 2009). There are two muscle attachment sites on the proximal femur, the lesser and greater trochanters found on the posterior-medial and superior-lateral aspects, respectively. Due to layers of cartilage on the surface of the femoral head and acetabulum, there is low friction articulation and load transferals across the hip joint (Bellucci, 2001; Teshima, 1995).

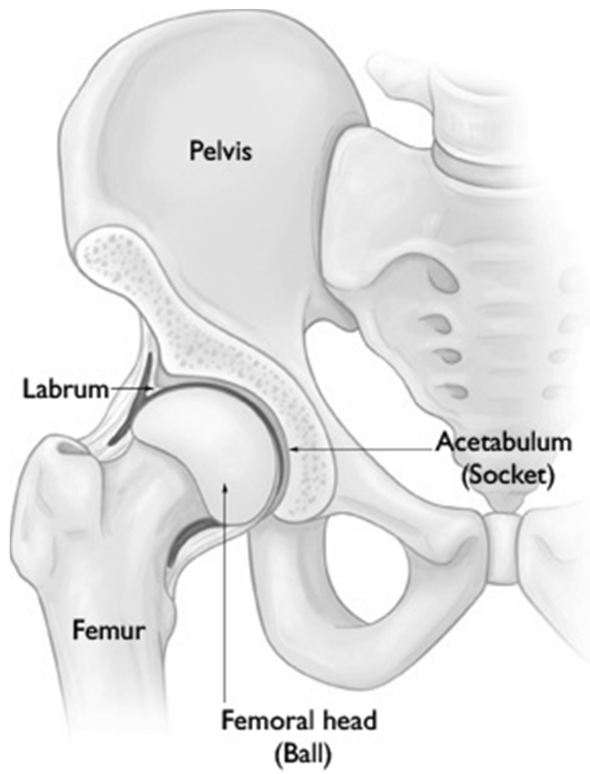

Figure 1.1 Anatomy of Hip Joint (http://orthoinfo.aaos.org/)

The hip capsule and surrounding reinforcement ligaments surrounding the hip adds to the dynamic stability of the joint. Example of key ligaments are the ishiofemoral ligament, the iliofemoral ligament, and the pubofemoral ligament (Polkowski, 2010). The ishiofemoral ligament covers the hip posteriorly and acts to limit internal rotation and hip adduction with flexion. The iliofemoral ligament covers the hip anteriorly and acts to limit extension and external rotation. Lastly, the pubofemoral ligament also covers the hip anteriorly and acts to limit abduction and hyperextension. Together, these ligaments become tighter during extension therefore the hip exhibits larger ranges of rotational motion in flexion compared to extension (Sim, 1995). In addition, several muscles line the outside of the hip to help generate motion between the pelvis and lower limbs. These muscles act as hip flexors/extensors, hip adductors/abdutors, and hip internal/external rotators. The hip acts as a multiaxial ball and socket joint, with motion almost entirely stemming from rotational motion rather than translational motion, due to the congruency of the articulating contacts (Simon, 2000). This high degree of compatibility stems from the bony morphology, labrum, articular cartilage, capsule, and surrounding musculature. Working together to limit the hip to a maximum of 120º flexion, 10º extension, 45º abduction, 25º adduction, 15º internal rotation, and 35º of external rotation in the typical person (Simon, 2000).

The acetabulum is entirely lined by a fibrocartilaginous structure known as the labrum. The acetabular labrum is 22% of the articulating surface of the hip and adds 33% to the volume of the acetabulum (Simon, 2000). It is a C-shaped fibrocartilaginous structure with an opening anterinferiorly at the site of the acetabular notch and is bridged to the pelvis with transverse ligaments. The labrum has a triangular cross-section and is thickest posterosuperiorly and widest anterosuperiorly. The external surface of the fibrocartilage is circumferentially orientated layer with radial reinforcing filaments. The middle layer is a dense lamellar collagenous layer and the articular surface is a randomly oriented fibrillary layer with chondrocytes. In addition, mechanically it limits extreme ranges of motion and adds stability to the hip joint. The labrum also acts as a seal around the joint, creating a negative pressure holding the joint together (Kapandji, 1970) and provides lubrication to the articulating surfaces by preventing synovial fluid movement out of the intraarticular space (Ferguson, 2000).

Femoroacetabular Impingement

Femoroacetabular impingement (FAI) in the hip is defined as the abnormal bone morphology in the proximal femur (ball) and/or the acetabulum rim (socket). Specifically, FAI results from bone spurs on the antero-superior femoral head-neck junction (the top of the femoral head) and the antero-superior rim of the acetabulum (top of the acetabulum) and it is associated with a pathomechanical environment (Ganz, 2003). The abnormality often leads to pain in the hip, a reduced range of motion, and can lead to an early degenerative disease in the hip such as osteoarthritis. In addition, if the condition is not repaired with surgery patients may experience cartilage damage, hyperlaxity, sports hernias, and lower back pain.

Figure 1.2 Bone Spurs on Hip Joints (www.snpatiented.com)

There are two major subtypes of FAI, cam FAI and pincer FAI, each with its own distinct injury mechanisms (Ganz 2003, Byrd 2011). Cam impingement is the femoral head is not round and cannot rotate smoothly inside the acetabulum. A bump forms on the edge of the femoral head that grinds the cartilage inside the acetabulum. It leads to Shear stress is generated at the junction between the labrum and the cartilage causing outward avulsion of the labrum and/or an inward compression of the articular cartilage at Antero-superior Rim during flexion and internal rotation as the abnormally shaped and oversized femoral head is forcefully moved into the acetabulum (Ganz 2003). Cam impingement is often found in young, active male patients around the average age of 32 (Parvizi, 2007).

Pincer FAI is occurs when extra bone extends out over the normal rim of the acetabulum. Over coverage may arise from a variety of conditions such as when the pelvic socket is turned posteriorly or when the femoral head extends into the pelvis or if the hip socket is too deep or through labral ossification. This leads to an injury in which the anterior labrum is pinched between the bony structure caused by a linear contact between the acetabular rim and femoral head/neck (Ganz 2003). When left untreated, the acetabular labrum continues to degenerate or ossify and can lead to a leveraging effect of the femoral neck on the anterior rim of the acetabulum. However, unlike cam type FAI, chondral lesions and labral damage accompanied with pincer FAI is generally limited to a narrower area on the rim. Additionally, pincer type FAI is more commonly found in athletic, middle aged women around the average age of 40 (Ganz, 2003). The most common presentation of femoroacetabular impingement, however, is a mixer of both cam and pincer (Ganz, 2003).

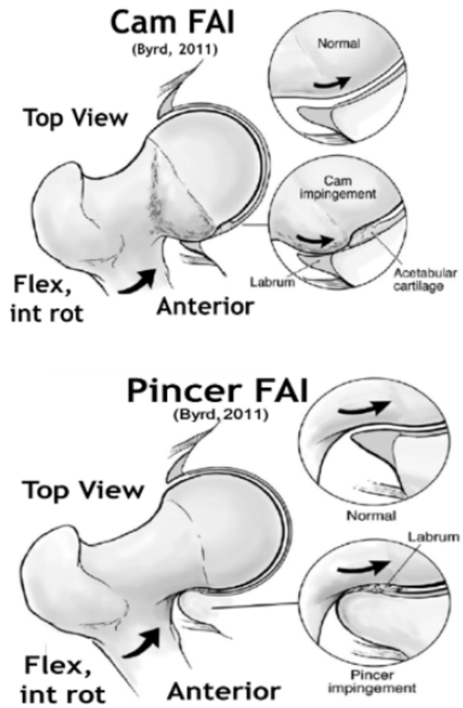

Figure 1.3 Cam vs. Pincer FAI (Byrd, 2011)

FAI is typically presented in active young or middle-aged patients, who often begin to have symptoms insidiously or after a minor trauma. Patients with FAI usually have pain in the groin area, although the pain sometimes may be more toward the outside of the hip. They may also have mechanical symptoms such as the hip locking, catching, or giving way (Kaplan, 2010). In a study done by Burnett and colleagues, they reviewed 66 patients with FAI pain; 91% of their patients had activity related pain and 47% had night pain (Burnett, 2006). A physical examination for FAI demonstrates a normal neurovacscular examination, no deficit in motor strength, and a reduced range of motion in internal rotation and adduction. Physicians use a variety of test to confirm their diagnosis of FAI, the most popular being the anterior impingement test and the posteroinferior impingement (Parvizi, 2007). During the anterior impingement test, the patient lies in the supine position and the physician brings the knee up towards the chest and then rotate it inward towards the opposite shoulder. The posteroinferior impingement test is also performed with the patient in the supine position; however, the patient slides to the edge of the examination table and extends the hip, while the physician passively externally rotates the hip. If this recreates your hip pain, the test result is positive for impingement (Parvizi, 2007).

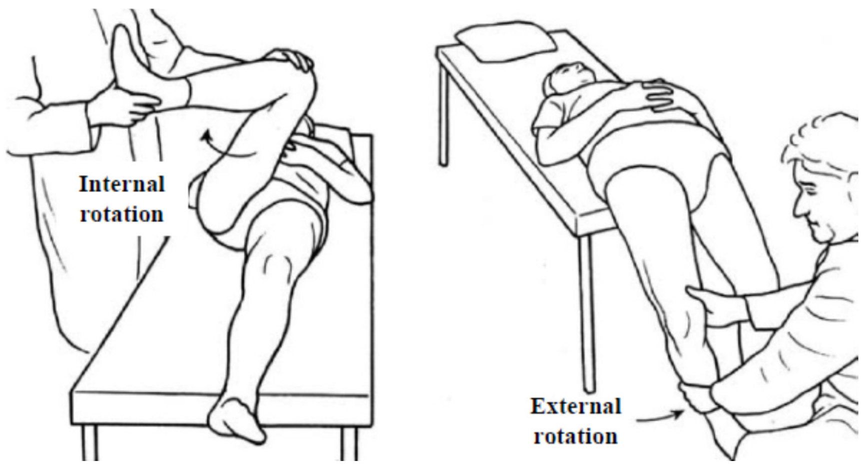

Figure 1.4 Anterior impingement test (left) to measure hip adduction and internal rotation while the hip is in 90° of flexion and posteroinferior impingement test (right) measures hip external rotation (Parvizi,2007).

Treatment Options

Damage to the labrum and acetabular cartilage is thought to occur primarily from shear forces produced by the abnormal bone morphology in both types of FAI, leading to damage primarily found in the anterior-superior (front, upper) region of the hip. The location of the injury implies that impingement and damage occurs when the hip is moved into internal rotation and adduction while in flexion or extension (Ganz, 2003). Since the FAI injury mechanism is mechanical in nature, treatment regiments must address the altered mechanics to be effective. Surgical treatments to remove the excess bone and repair the soft tissue is common, but there are still controversies about candidacy for surgery, the surgery approach, and the long term outcome from surgical treatment (Papalia, 2012). There is a lack of long term outcome results and evidence that intervention will reduce the risk of an FAI individual developing premature hip osteoarthritis (Papalia, 2012). There is also a growing concern that surgical intervention to treat FAI is applied too broadly and that conservative treatments should be further developed and considered in patients who lack considerable damage in the hip (Reiman 2014). Additionally, surgical treatments lend themselves towards a costly procedure and a timely recovery.

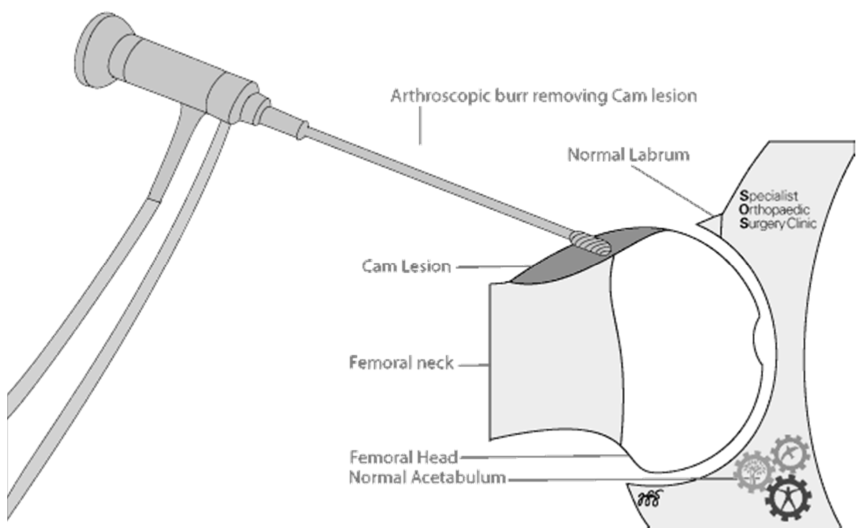

Figure 1.5 Surgical Treatment for FAI (http://orthoinfo.aaos.org)

The idea that treatments for FAI should address the mechanical nature of injury is not followed in the majority of conservative treatments that aim to mask pain through pharmaceuticals. Instead, these treatments have been found to be counterproductive (Parvizi 2007). Activity avoidance is another common conservative treatment, but due to the young and active nature of FAI individuals, compliance is often difficult and this method fails to control the symptoms. However, conservative treatments aimed at addressing the underlying injury mechanism in a group with mild FAI have been found to be effective at two year follow-up (Emara, 2011). Emara described the purpose of their conservative treatment to reduce pain and avoid further cartilage damage by modifying activities of daily living to adapt to the morphology, without limiting the level of activity (Emara, 2011). More specifically, Emara prescribed a treatment regimen aimed at re-teaching FAI individuals with labral tear but without signs of hip osteoarthritis how to reduce internal rotation and adduction when performing activities of daily living. Patient satisfaction and pain reduction at two year follow-up were similar to those reported for surgical intervention (Emara, 2011).

Braces have been suggested as a tool to aid in altering motion to limit pain and joint damage in FAI individuals. Lee proposed the use of a Stability thru External Rotation of the Femur (SERF) hip brace (Don Joy Orthopedics Inc, Vista, Ca) as a brace which was originally developed with the purpose of treating knee pain stemming from abnormal hip motion that could also help FAI patients (Lee, 2012). The design of the brace is a sleeve that fits over the knee and an elastic band that runs from the medial side of the knee over the thigh and then wraps around the waist. The line of action and the elasticity of the strapping brace limited internal rotation and adduction and was intended to provide abduction and external rotation torques to the hip during functional activities (Lee, 2012). In a case study, Austin utilized the SERF Brace to reduce adduction and internal rotation during various activities including a step-down and drop-jump exercise (Austin, 2008). In a single subject, Austin found that the brace drastically reduced both motions as well as pain. He suggested that excessive internal rotation and adduction contributed to labral damage and pain experienced by FAI patients and by reducing these motions, the brace can help in reducing the mechanical injury mechanism (Austin, 2008).

Figure 1.6 SERF Brace

The findings of the above studies suggest that a conservative methods aimed at motion modification to adjust to the abnormal morphology might be an effective means of treatment in individuals with mild FAI. A brace may also be an effective means of reducing symptoms and limiting further joint damage in a group of patients who are trying to prolong their athletic season or delay surgical intervention. Other braces, in addition to the SERF Brace, already on the market for other uses could be potentially used to address the injury mechanism faced by FAI patients. For example, the Groin Brace developed by Kinetic Innovation (Figure 1.6) (Kinetic Innovations, Omaha, NE) when modified with the tubing being pulled posteriorly towards the coccyx could be a potential conservative treatment option. With the tubing being pulled up, towards the back, the modified brace's (Figure 1.7) new line of action should externally rotate and abduct the hip. In addition, braces compared to other conservative treatments could improve the compliance in younger, active groups of individuals and could provide patients with FAI as a means to reduce pain and prevent further joint damage while the patient is waiting for the surgical treatment.

Figure 1.7 Kinetic Innovation Groin Brace

Figure 1.8 Modified Groin Brace Used in Study

The purpose of this study was to characterize the kinematic effects at the hip in healthy individuals with various braces to identify potential conservative alternative for FAI treatments. We believe that the SERF Brace and Groin Brace will reduce adduction and increase external rotation of the hip. In addition, to fully develop a hip brace as a full conservative treatment option for FAI patients, the brace's effectiveness between different activities must be analyzed. Therefore, this study with healthy control subjects characterizing each of the proposed braces is stage one of a two stage study. Before utilizing the brace in clinical trials with actual FAI patients, each brace must be fully characterize as one that abducts and externally rotates the hip

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CHAPTER TWO

Methods

2.1 Subjects

Five healthy, control individuals were enrolled in this study. The study was approved by the Baylor University Internal Review Board before participants were enrolled. Each volunteer signed an informed written consent before participating in the study. Exclusion criteria for this study included not being between the ages of 18 to 50 years old, any condition or prior injury that potentially alter normal motion, BMI > 30, blindness, currently pregnant, and if the subjects was unable to maintain moderate, intermittent physical activity for an extended period of time. The subject demographics for this study can be found in Table 2.1.

Table 2.1 Subject Demographic

	Gender	Age	BMI
Control Subjects	5M	21 (0.8)	23.3 (2.6)

2.2 Motion Capture Procedure

Three dimensional lower limb kinematics were collected using a fourteen camera opteoelectronic system by Vicon at 120Hz and a multicomponent forceplate by AMTI fixed flush with the ground in the middle of the walkway. 57 passive reflective markers were placed on anatomical landmarks according to previously described method by Wilken as shown in Figure 2.1 (Wilken, 2012). Subjects were asked to wear asked to wear sportswear so that the markers could be placed directly on the body and clothing would not block the view from any of the cameras. In addition, each subject was asked to wear athletic shoes with minimum reflective material on it to stimulate actual walking and jogging activities in daily living.

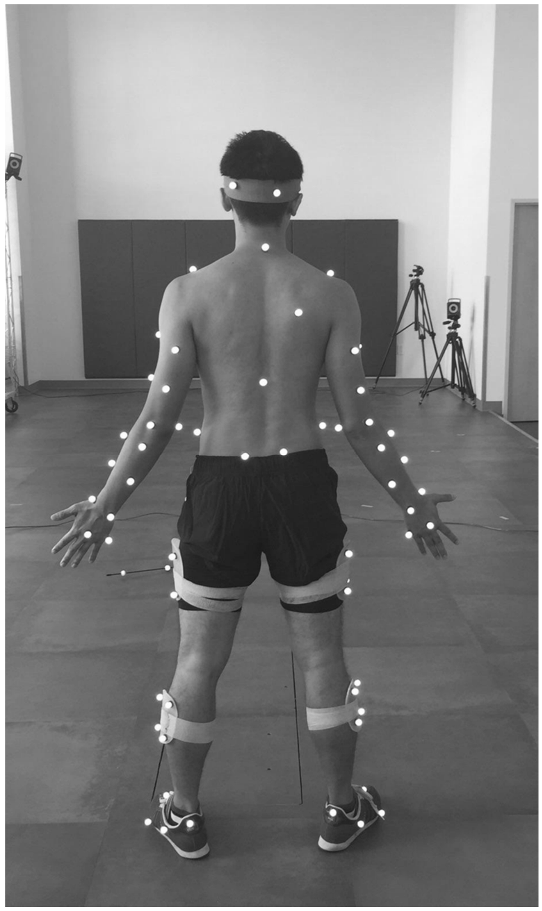

Figure 2.1 Marker Placement

Hip kinematics were collected for the right limb while the patients walked at a slow walking speed (Froude 2), fast walking speed (Froude 4), and a self-selected jogging speed using Vicon Nexus 2.1. The equations used to calculate the walking speed at Froude 2 and 4 respectfully are $\mathrm{v} = 0.32 \times \sqrt{g \times l}$ and $\mathrm{v} = 0.48 \times \sqrt{g \times l}$, where g is gravity and l is leg length. During each trial, each subject was asked to walk within ±5% of their calculated Froude speed for their respective leg length and monitored to stay within that frame so all the subjects could be normalized to the same relative speed. Each subject was asked to pick a comfortable, self-selected, constant jogging speed that would be utilized is all three cases.

First, a static trial was collected with the subject standing still, palms out and feet shoulder length apart. A range of motion trial followed the static trial and was used to calibrate the subject and label each marker as their respective anatomical position in Vicon Nexus (Figure 2.2). Then a digitize trial was collected using a “wand” to place virtual markers on the subject joints to be used in post processing. Three trials for each activity were collected with the subject wearing no brace. New static, range of motion, and digitize trial were collected after the subject put on the SERF Brace (Figure 2.3) due to the alteration in marker placements caused by the brace. Then three trials for each activity was collected with the subject wearing the SERF Brace. Lastly, another set of static, range of motion, and digitize trials were collected with the subject wearing the modified Groin Brace (Figure 2.4). The Groin Brace was modified from its original design by rather having the bands stretched across the groin to being attached posteriorly across the thigh. The three activities were repeated for three trials each with the Groin Brace.

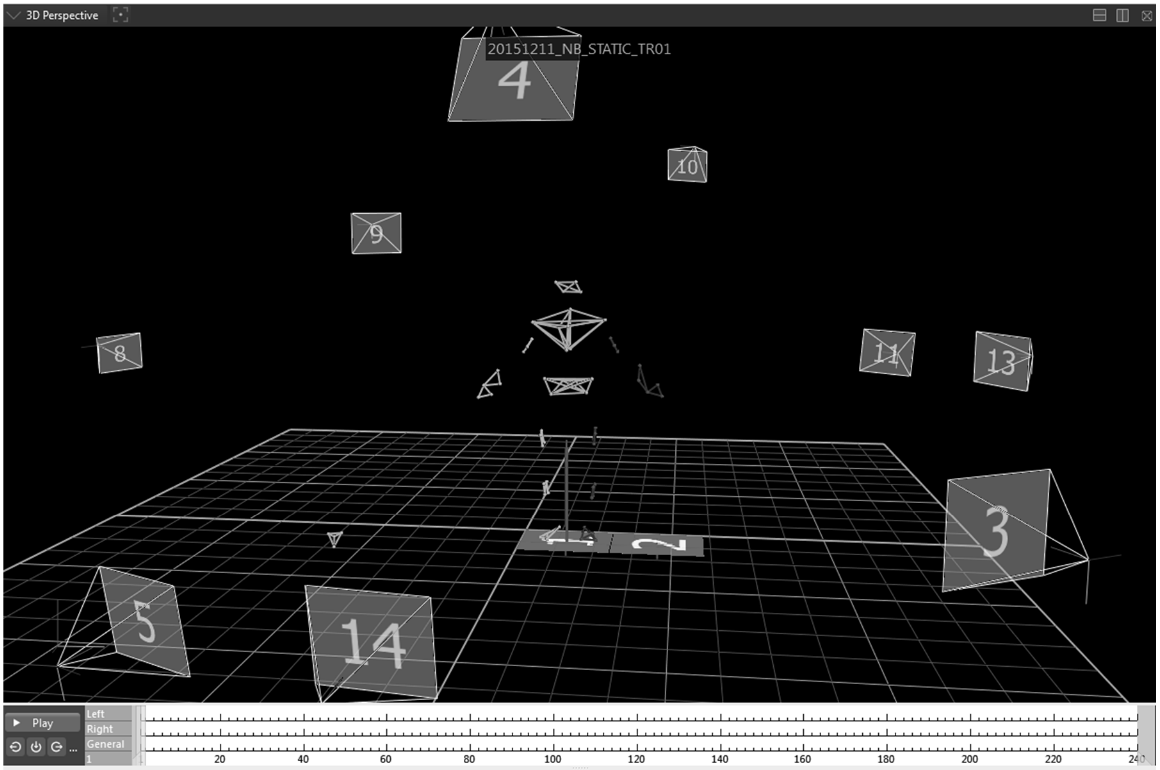

Figure 2.2 Markers Labeled and Model Created in Nexus

Figure 2.3 SERF Brace

Figure 2.4 Modified Groin Brace from Kinetic Innovation

2.3 Post Processing

The data was then inspected for gaps (when markers disappeared momentarily or become unlabeled) and filled using a variety of methods such as spline, rigid body, and pattern filling. The clean data was then exported from Vicon Nexus to Visual3D V5 Professional™ to calculate peak hip flexion, extension, abduction, adduction, internal rotation, and external for each trial. The static trial was imported into Visual3D to find the marker placement for each subject. Then the digitize trial was used to find the various joint centers on the body (Figure 2.5). In particular, the right and left anterior and posterior iliac crest markers are used to calculate the hip joint center and the medial and lateral knee digitizing markers are used to calculate the knee joint center. A model was then created base on the subject's height and weight (Figure 2.6). The coordinate axis for the right hip was calculated using the right hip joint center, lateral digitizing knee marker, and the medial digitizing knee marker. The hip utilized the right and left greater trochanter digitize markers to find its coordinate axis.

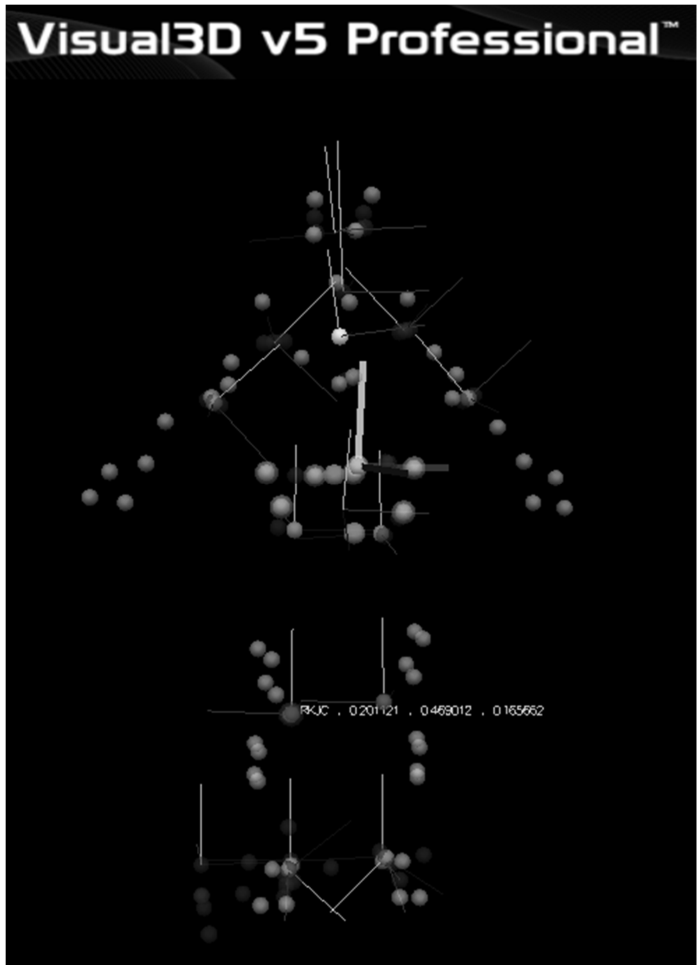

Figure 2.5 Landmarks and Joint Centers of the Subject in Visual 3D

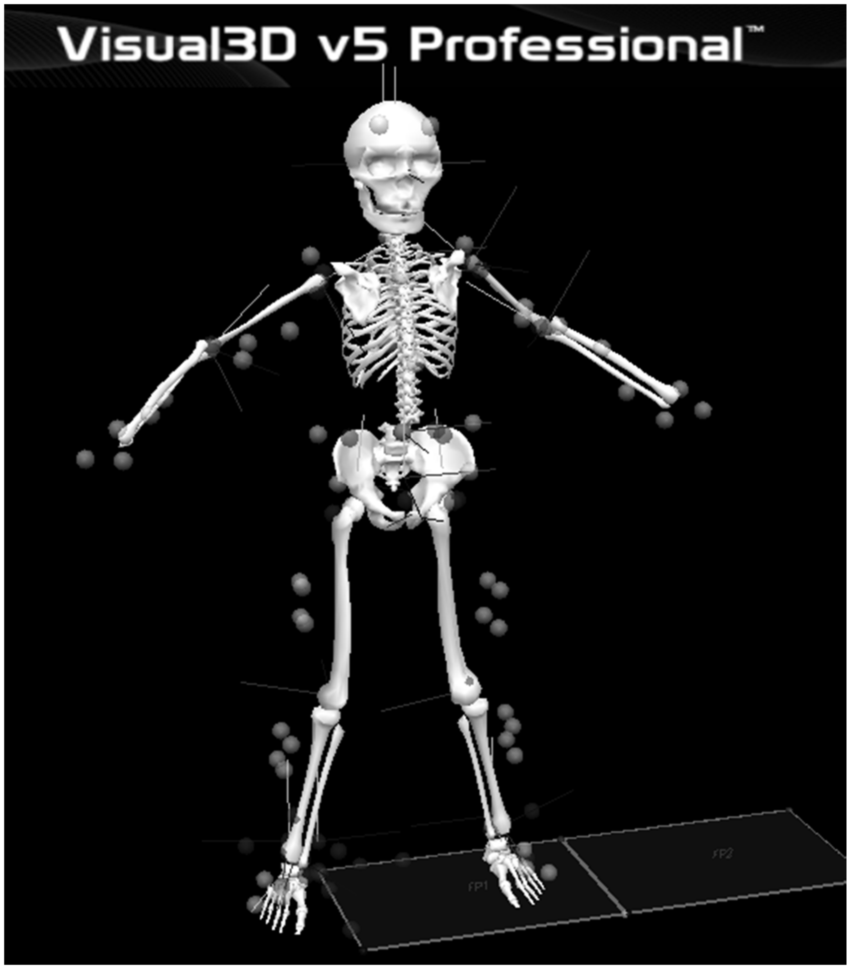

Figure 2.6 Model Created of Subject in Visual3D

Next each trial was imported, nine per subject per brace plus the static trial to find the neutral angles, and a pipeline was ran to find the gait events for each trial using the force plate data collected in Vicon Nexus (Figure 2.7). Lastly, the hip kinematics were calculated based on the gait events and the data was ready to exported to Matlab R2015a (MathWorks, Natick, MA) for further analysis.

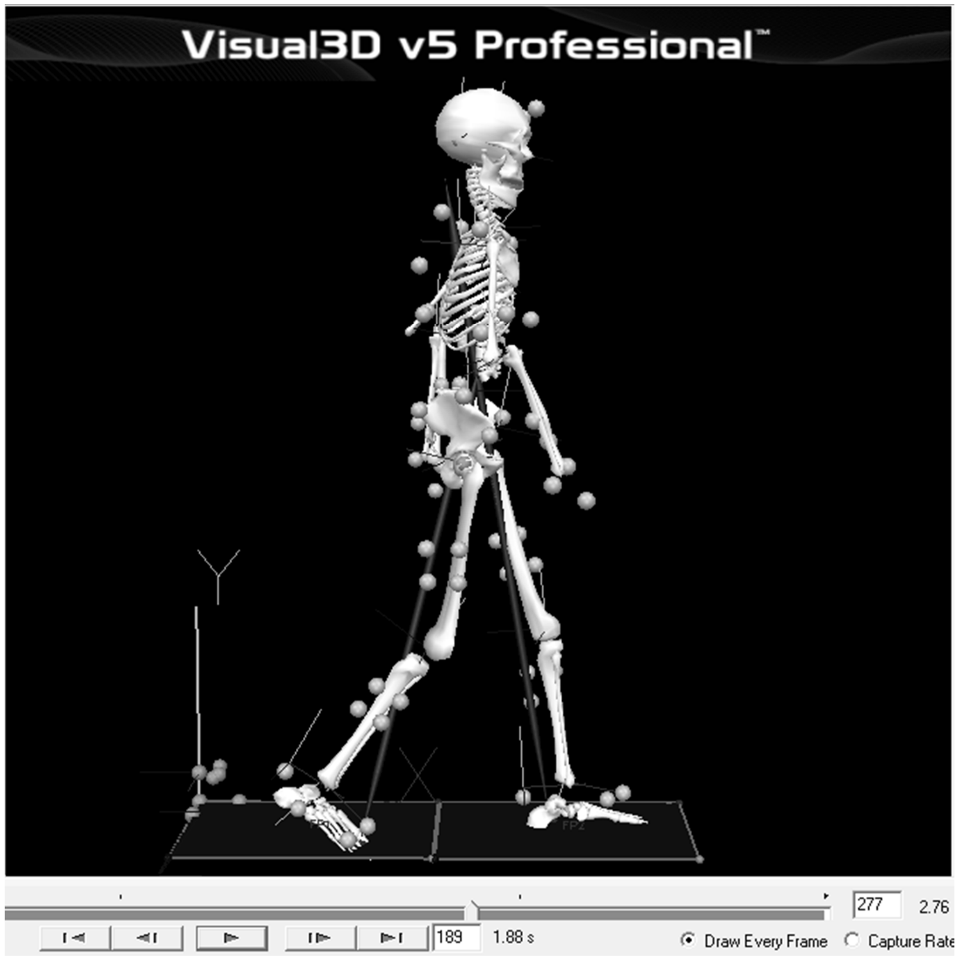

Figure 2.7 Walking Trial in Visual3D

The data was then exported from Visual3D to a Matlab file to be processed further. Using the coordinate for heel and pelvic markers, gait events were calculated. Matlab utilized the markers to identify the first complete stance phase from right heel strike to right heel strike. It than calculated the maximum peak values for flexion, extension, abduction, adduction, internal rotation, and external rotation that was exported as various hip angles in the x, y, and z plane from Visual3D.

2.4 Statistics

Several statistics were calculated to help understand our hypothesis better. Averages and standard deviations for the peak values of each motion were calculated over the three trials for each activity for each of the three conditions (no brace, SERF Brace and Groin Brace). Then a p-value was calculated using a two-paired t-test comparing both brace condition to the no brace condition for each activity (Table 3.1 and 3.2). P-values less than 0.05 were categorized as being significant. A comparison was made between the change in hip motion peak values within the same condition but different activities (Table 3.3 and 3.4). For example, the change in hip flexion during slow walking from wearing no brace to SERF Brace was compared to the change in hip flexion during fast walking from no brace to SERF Brace. Likewise for the jogging trial and for the other brace comparison. Lastly, the sagittal (flexion and extension), frontal (abduction and adduction) and transverse (external and internal rotation) ranges of motion were calculated and averaged together for each condition comparison (Table 3.5 and 3.6).

CHAPTER THREE

Results

3.1 Comparison Among Braces

Table 3.1 Comparison of peak hip angles (degrees) for flexion, extension, abduction, adduction, internal rotation, and external rotation for No Brace vs. SERF Brace. All stated parameters are reported as positive in their indicated direction (ex. A negative value for hip extension means hip flexion).

		Flexion	Extension	Abduction	Adduction	External Rotation	Internal Rotation
Slow Walking	No Brace	21.57 (3.9)	11.80 (3.0)	4.37 (4.6)	6.37 (4.9)	5.14 (1.8)	1.73 (1.7)
	SERF Brace	22.91 (3.2)	11.98 (3.4)	5.19 (7.09)	3.55 (7.7)	6.33 (1.7)	1.79 (3.3)
	P-Value	0.80	0.42	0.83	0.38	0.45	0.99
Fast Walking	No Brace	25.86 (3.4)	14.75 (2.4)	5.03 (4.5)	5.98 (3.2)	6.85 (3.3)	1.62 (2.4)
	SERF Brace	28.04 (2.8)	14.49 (4.0)	5.71 (7.3)	3.86 (7.1)	7.60 (2.1)	2.72 (4.2)
	P-Value	0.44	0.99	0.69	0.64	0.92	0.83
Slow Jogging	No Brace	27.54 (2.9)	5.16 (2.5)	9.58 (4.8)	4.08 (5.5)	8.62 (3.6)	-1.13 (2.0)
	SERF Brace	26.56 (3.6)	8.16 (3.67)	6.78 (6.88)	2.45 (6.58)	8.78 (2.3)	-1.41 (3.6)
	P-Value	0.18	0.11	0.10	0.95	0.52	0.99

Table 3.2 Comparison of peak hip angles (degrees) for flexion, extension, abduction, adduction, internal rotation, and external rotation for No Brace vs. Groin Brace. All stated parameters are reported as positive in their indicated direction (ex. A negative value for hip extension means hip flexion).

		Flexion	Extension	Abduction	Adduction	External Rotation	Internal Rotation
Slow Walking	No Brace	21.57 (3.9)	11.80 (3.0)	4.37 (4.6)	6.37 (4.9)	5.14 (1.8)	1.73 (1.7)
	Groin Brace	19.22 (3.9)	13.25 (2.93	6.08 (1.41)	1.38 (2.5)	10.74 (2.6)	-4.08 (3.4)
	P-Value	0.02	0.18	0.67	0.03	0.04	0.04
Fast Walking	No Brace	25.86 (3.4)	14.75 (2.4)	5.03 (4.5)	5.98 (3.2)	6.85 (3.3)	1.62 (2.4)
	Groin Brace	24.90 (5.7)	15.87 (4.0)	7.75 (1.64)	0.37 (2.73)	11.19 (2.3)	-3.1 (4.7)
	P-Value	0.57	0.38	0.27	0.01	0.03	0.09
Slow Jogging	No Brace	27.54 (2.9)	5.16 (2.5)	9.58 (4.8)	4.08 (5.5)	8.62 (3.6)	-1.13 (2.0)
	Groin Brace	25.20 (3.1)	5.80 (2.9)	8.84 (2.9)	2.91 (3.2)	13.05 (2.5)	5.96 (2.7)
	P-Value	0.41	0.24	0.51	0.43	0.03	0.05

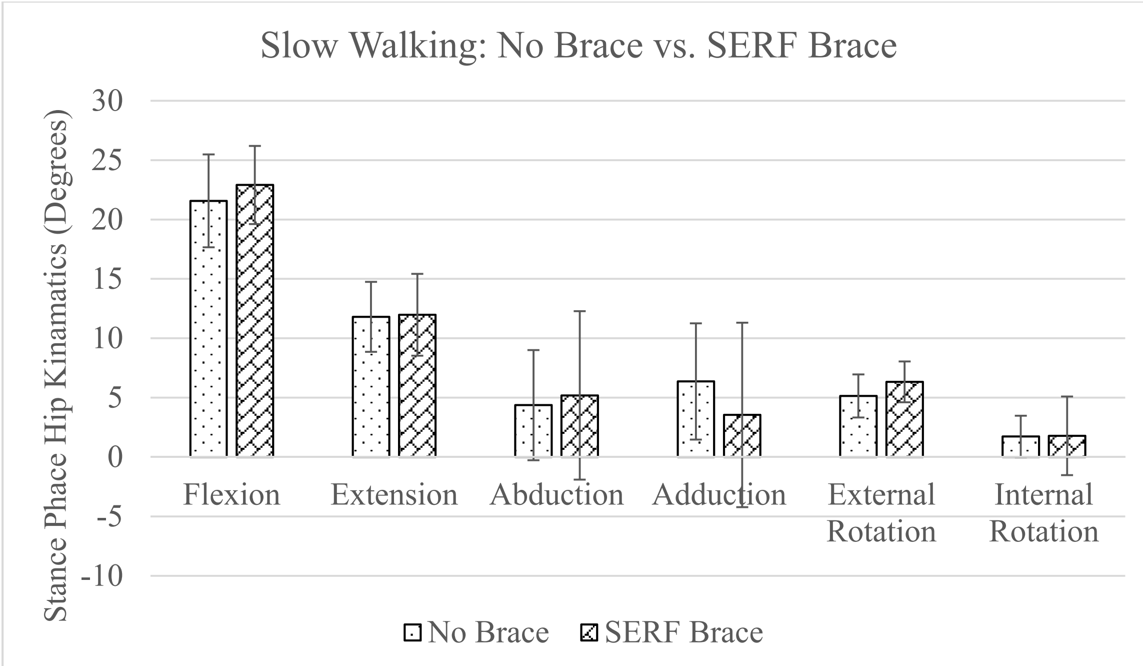

Figure 3.1 Average peak hip angle for no brace vs. SERF Brace during slow walking trials. All stated parameters are reported as positive in their indicated direction (ex. A negative value for hip extension means hip flexion).

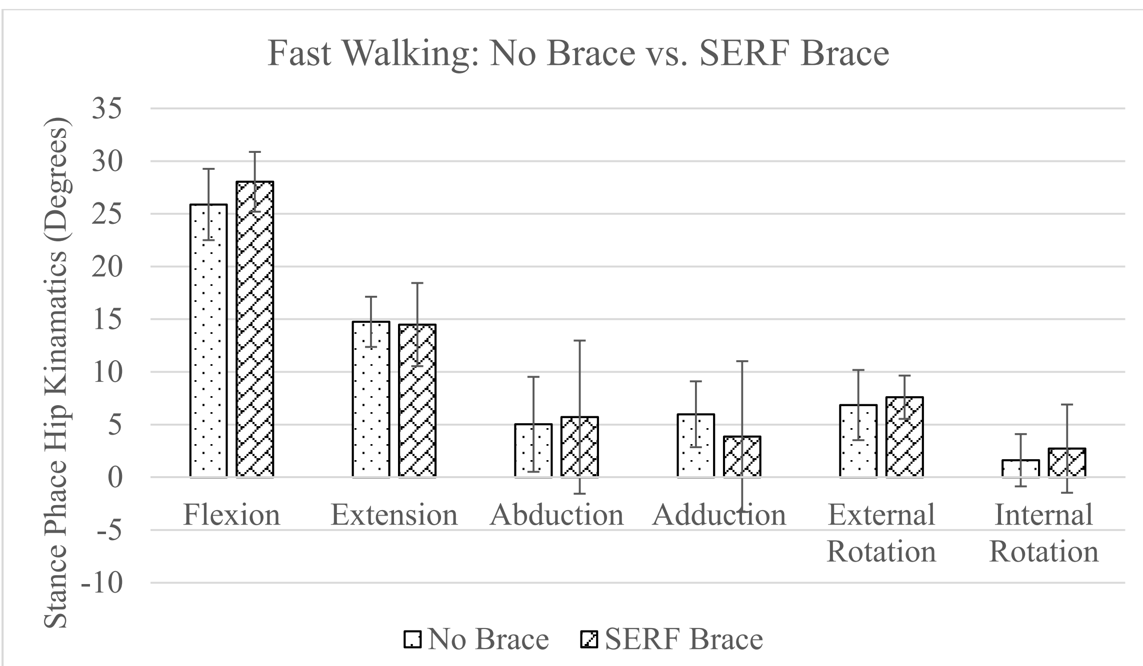

Figure 3.2 Average peak hip angle for no brace vs. SERF Brace during fast walking trials. All stated parameters are reported as positive in their indicated direction (ex. A negative value for hip extension means hip flexion).

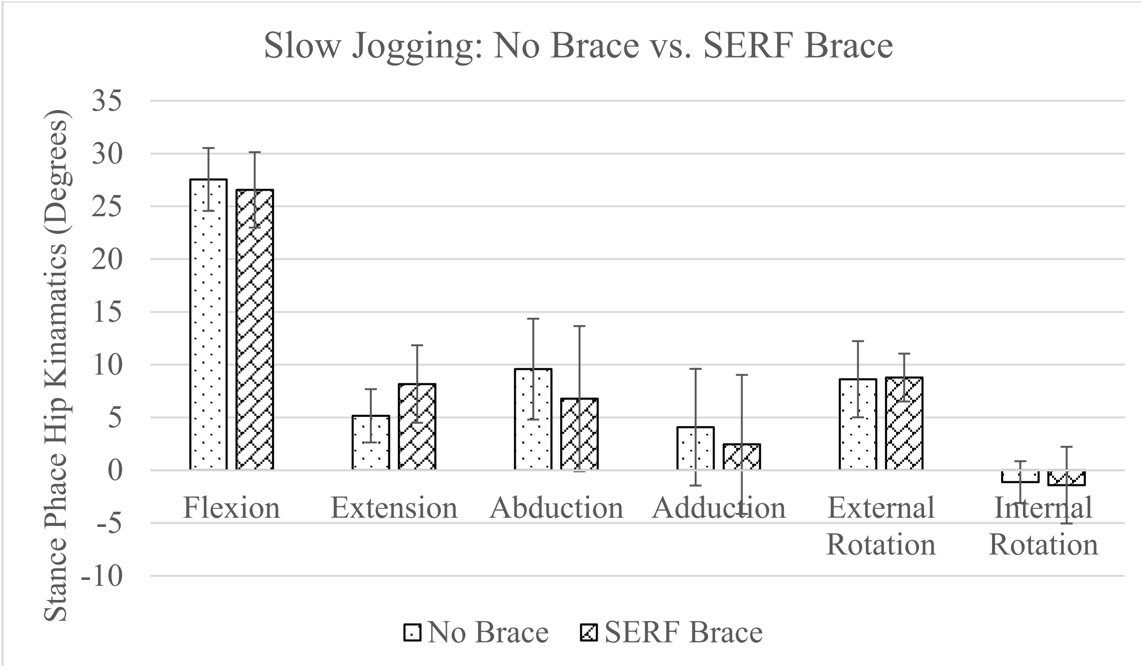

Figure 3.3 Average peak hip angle for no brace vs. SERF Brace during slow jogging trials. All stated parameters are reported as positive in their indicated direction (ex. A negative value for hip extension means hip flexion).

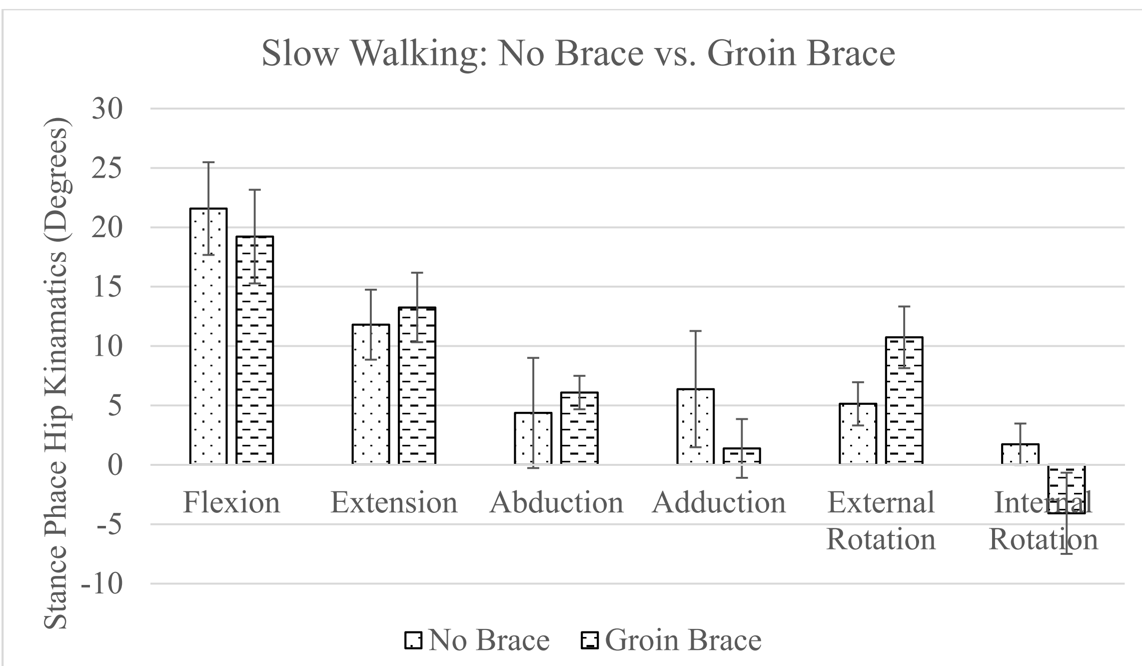

Figure 3.4 Average peak hip angle for no brace vs. Groin Brace during slow walking trials. All stated parameters are reported as positive in their indicated direction (ex. A negative value for hip extension means hip flexion).

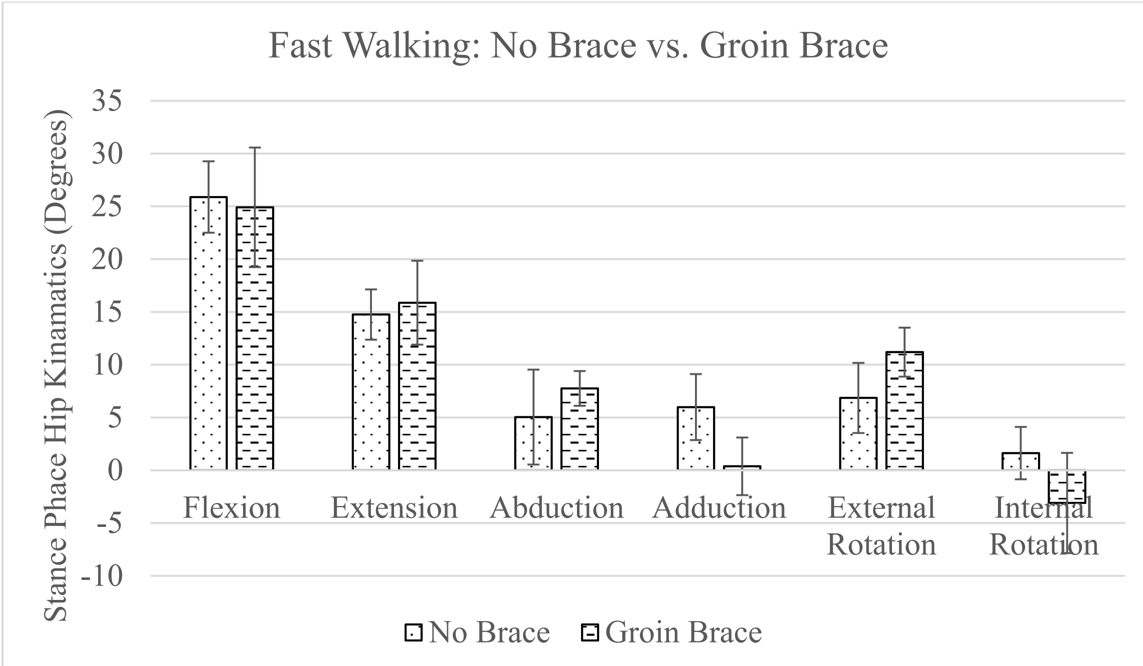

Figure 3.5 Average peak hip angle for no brace vs. Groin Brace during fast walking trials. All stated parameters are reported as positive in their indicated direction (ex. A negative value for hip extension means hip flexion).

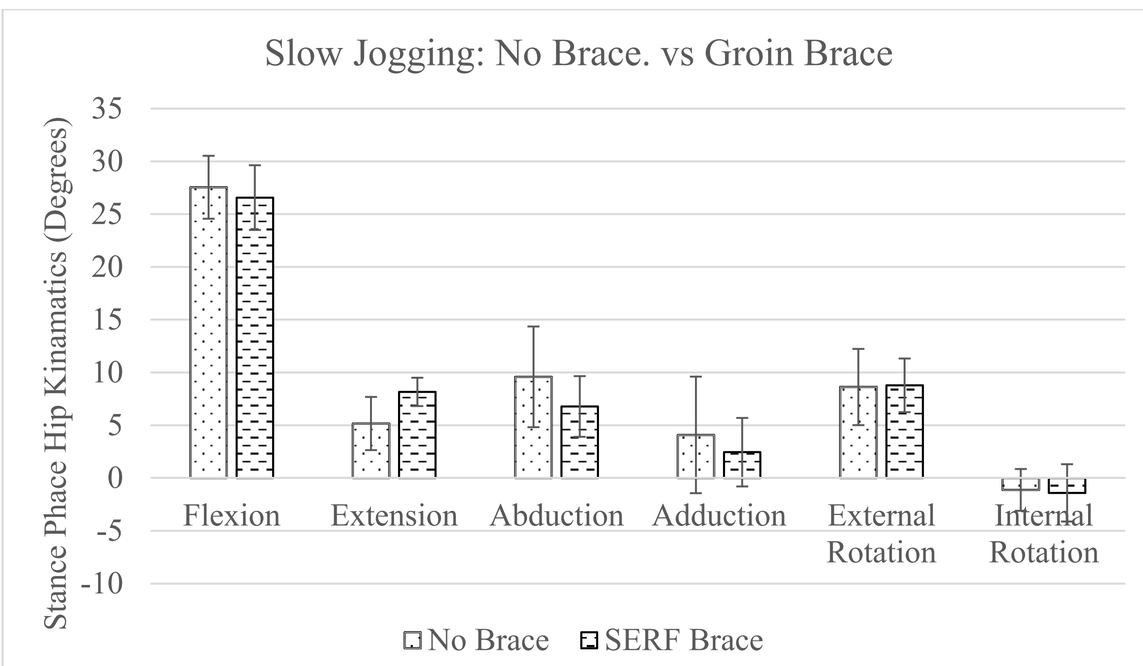

Figure 3.6 Average peak hip angle for no brace vs. Groin brace during slow jogging trials. All stated parameters are reported as positive in their indicated direction (ex. A negative value for hip extension means hip flexion).

3.2 Comparison Between Activities

Table 3.3 Difference between peak hip angle (degrees) of no brace compared to SERF Brace ($p<0.05$). All stated parameters are reported as positive in their indicated direction (ex. A negative value for hip extension means hip flexion).

No Brace vs. SERF Brace	Flexion	Extension	Abduction	Adduction	External Rotation	Internal Rotation
Slow Walking	1.33	0.18	0.82	-2.82	1.19	0.07
Fast Walking	2.16	-0.26	0.67	-2.13	0.76	1.10
Slow Jogging	-0.98	3.00	-2.80	-1.63	0.16	-0.28
P-Value for Slow Walking vs. Fast Walking	0.33	0.69	0.58	0.29	0.54	0.58
P-Value for Fast Walking vs. Slow Jogging	0.06	0.13	0.58	0.51	0.21	0.36
P-Value for Slow Walking vs. Slow Jogging	0.51	0.14	0.11	0.41	0.36	0.96

Table 3.4 Difference between peak hip angle (degrees) of no brace compared to Groin brace ($p<0.05$). All stated parameters are reported as positive in their indicated direction (ex. A negative value for hip extension means hip flexion).

No Brace vs. Groin Brace	Flexion	Extension	Abduction	Adduction	External Rotation	Internal Rotation
Slow Walking	-2.36	1.45	1.71	-4.99	5.60	-5.81
Fast Walking	-0.97	1.11	2.71	-5.61	4.34	-4.72
Slow Jogging	-2.34	0.63	-0.75	-1.17	4.43	-4.83
P-Value for Slow Walking vs. Fast Walking	0.35	0.74	0.26	0.25	0.44	0.42
P-Value for Fast Walking vs. Slow Jogging	0.67	0.65	0.10	0.15	0.83	0.71
P-Value for Slow Walking vs. Slow Jogging	0.54	0.40	0.06	0.18	0.37	0.39

3.3 Range of Motions

Table 3.5 Range of motion (degrees) for no brace compared to SERF Brace (p<0.05).

		Sagittal ROM	Frontal ROM	Transverse ROM
Slow Walking	No Brace	33.38	10.74	6.86
	SERF Brace	34.89	8.73	8.12
	P-Value	0.91	0.40	0.86
Fast Walking	No Brace	40.63	11.02	8.46
	SERF Brace	42.53	9.57	10.32
	P-Value	0.91	0.40	0.86
Slow Jogging	No Brace	32.70	13.66	7.49
	SERF Brace	34.72	9.23	7.57
	P-Value	0.82	0.32	0.83

Table 3.6 Range of motion (degrees) for no brace compared to Groin Brace (p<0.05).

		Sagittal ROM	Frontal ROM	Transverse ROM
Slow Walking	No Brace	33.38	10.74	6.86
	Groin Brace	32.46	7.46	6.66
	P-Value	0.93	0.23	0.77
Fast Walking	No Brace	40.63	11.02	8.46
	Groin Brace	40.77	8.12	8.08
	P-Value	0.72	0.25	0.82
Slow Jogging	No Brace	32.70	13.66	7.49
	Groin Brace	31.00	11.75	7.09
	P-Value	0.11	0.45	0.59

3.4 Hip Angle Through Stance Phase

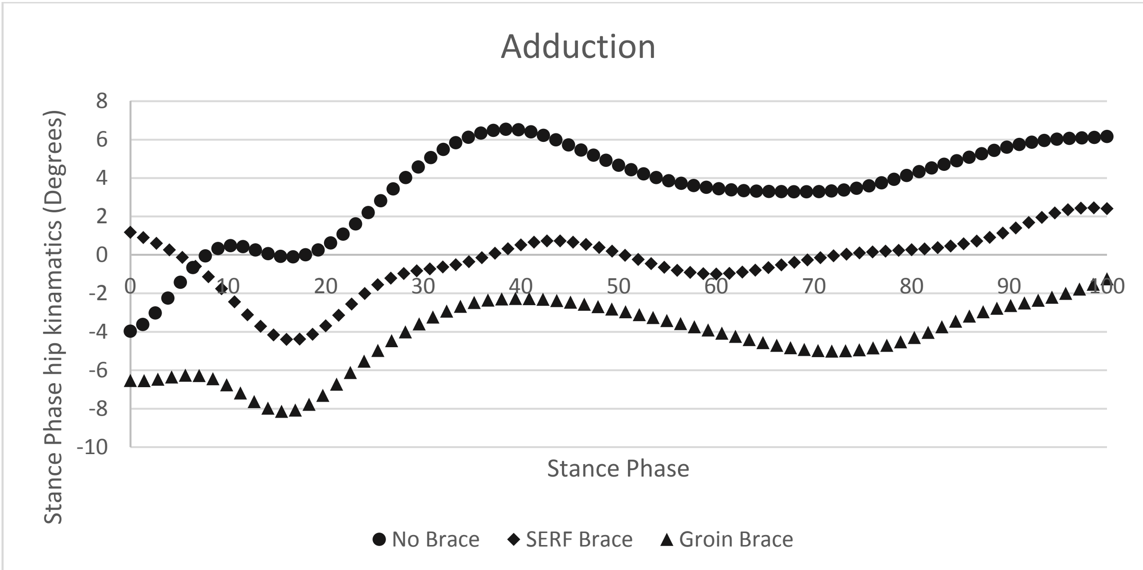

Figure 3.7 Adduction angle through phase stance for all three conditions. All stated parameters are reported as positive in their indicated direction (ex. A negative value for hip extension means hip flexion).

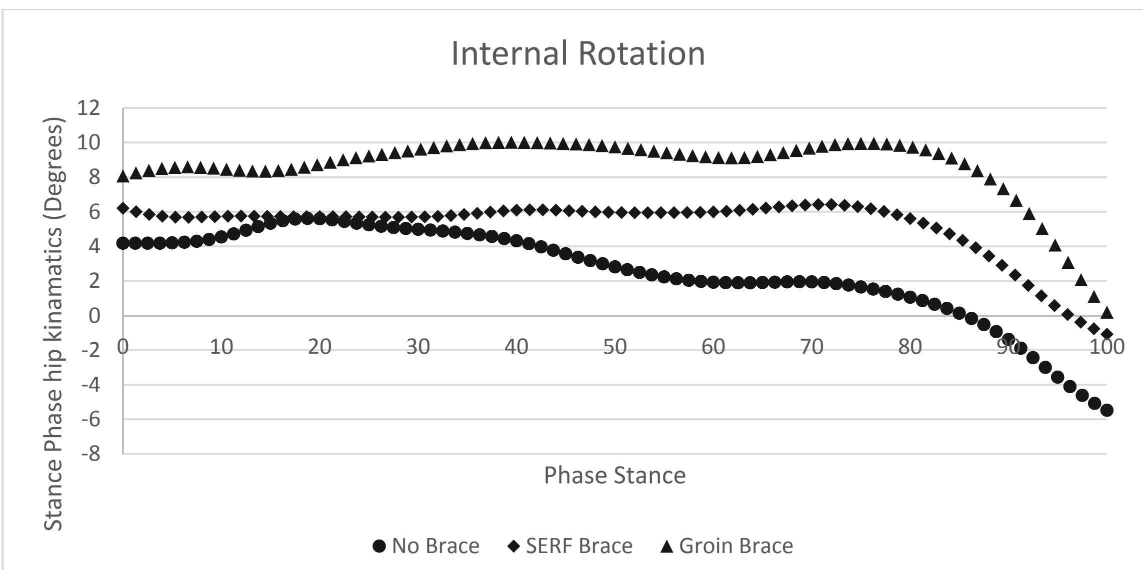

Figure 3.8 Internal rotation angle through phase stance for all three conditions. All stated parameters are reported as positive in their indicated direction (ex. A negative value for hip extension means hip flexion).

CHAPTER FOUR

Discussion and Conclusion

The results of this study support the hypothesis that the SERF and Groin Brace decreased hip adduction and increased external rotation during walking and jogging activities. Due to the anterior-superior location of most FAI bone morphology, these motions are thought to contribute to the injury mechanism of FAI. The results of this study indicate that these braces could be potential conservative treatment tools to reduce the motions that tend to lead to pain and soft tissue damage in individuals with FAI. As such, it is possible that patients waiting for surgery or trying to avoid surgery would benefit from using a brace along with their prescribed therapy regimen. Additionally, these braces may serve as an effective means to limit harmful motions after surgery for someone who has had their labrum repaired or had microfracture treatment for damaged cartilage.

Although both braces addressed the underlining injury mechanism for FAI, they had varying effects on hip flexion, extension, abduction, adduction, external rotation, and internal rotation based on speed and activity level. In addition, only the Groin Brace showed a statistically significance difference ($p<0.05$) in peak motions during the activities tested. The results from the SERF Brace in regards to increased flexion and internal rotation during both walking trails was not expected. On the other hand, the results from the Groin Brace for each hip motion were as predicted except for abduction during the jogging trial.

The walking trials for the SERF Brace showed increase in flexion, extension, abduction, external rotation, and internal rotation and a decrease in adduction. The increase in flexion could be because the brace pulls the leg up from the knee therefore causing it to be lifted higher during walking trials. The increase in internal rotation could be due to the brace being wrapped around the knee and being pulled inwards while walking trying to fight the tendency to pull it outwards. The changes in the other four motions were as predicted when considering the line of action of the SERF Braces is being pulled around the thigh, toward the back.

The alterations the Groin Brace had on the hip during walking trials were all as predicted. The line of action for the modified Groin Brace was from the lower thigh and around to back to the coccyx bone. Therefore, the tubing acted as synthetic muscles that actively tried to adduct and externally rotate the leg. It should also be noted that the internal rotation for the Groin Brace during walking trials was negative. This is significant because the negative value shows that hip was being externally rotated through the entire walking trial and never was internally rotated

During jogging, both braces had a different effect on peak hip abduction compared to walking. Both braces caused a reduction in abduction, but all of the other hip motions, including flexion and internal rotation for the SERF Brace, exhibited expected trends. Due to the high activity and motion of jogging, the muscles of the hip may have been over powering the hip braces effect of increasing abduction as seen in the walking trials.

As expected, the overall range of motion was affected by the hip brace. The SERF Brace caused an increase range of motion in the sagittal (flexion and extension) and transverse (external and internal rotation) plane but an increase in the frontal (abduction and adduction) plane. The Groin Brace decreased the range of motion in all the planes in all of the activities except the sagittal plane during fast walking, where it was increased. The SERF Brace probably caused an increase in range of motion due to the strap readjusting itself during each trial. The decrease in abduction and adduction could be due to how the brace is wrapped around the waist. The reduced range of motion in the Groin Brace is mostly likely due to the compression short material.

Based on peak hip motions, both braces addressed the underlining pathomechanical injury mechanism faced by FAI patients. However, due to the design of each brace they both had different magnitudes in changes of peak hip motion. For example, the Groin Brace had a greater effect on altering the hip kinematics compared to the SERF Brace. Therefore, the Groin Brace should have a greater effect on FAI patients on reducing adduction and internal rotation. This is most likely because the Groin Brace is worn as a pair of shorts and its effect on the hip is directly influenced by how hard the tubing is pulling on the adjustable strap. Due to the complexity of the SERF Brace, being wrapped around the knee, thigh, and waist, it is hard to get the full effects of the brace. In addition, over time the SERF Brace had a tendency to become loosen during the more strenuous activity, thus minimizing the effect it had on the hip.

To fully develop a conservative treatment using hip braces, limitations must be addressed of each brace in regards to how strenuous an activity can be. Unlike hip osteoarthritis patients who tend to be older patients, FAI patients tend to be young, active individually who partake in a variety of daily activities. For example, in addition to wearing the brace, does the patient need to also modify or avoid certain hip motions?

Based on the results from this study, the FAI patients should avoid activities with higher hip motions, such as jogging when using either brace. Although the hip adduction decreased and external rotation increase, both braces caused a reduction in abduction of the hip. In addition, during the jogging activity the SERF Brace and the strap of the Groin Brace tended to become loosen.

Despite the promising findings, only a small sample size of healthy males were collected at a single time point. In addition, there were several sources for experimental error. The most notable being the brace moving or altering itself in between trials, thus loosening the effect it had on the leg. Another source of error was when gap filling was utilized to fill in the missing marker in Nexus or when the braces came in contact with the thigh markers during activities. It was also very difficult to locate the knee joint center in individuals with a lot of lower leg muscle mass. As more patients were enrolled, the amount of experimental error decreased as seen in the quality of data collected in Nexus.

In conclusion, based on the results from this study both braces could be potentially used to address the injury mechanism experience by FAI patients. The two tested braces would have the most effect during low strenuous activities as compared to high motion activities. In addition, the Groin Brace showed to have significant differences in adduction and external rotation that makes it a promising choice to be used in stage 2 of this study, clinical trials. Although hip braces may not be able to cure FAI, they can help as a conservative treatment to levitate pain and in preventing further cartilage damage from occurring. The results of this study indicate that a hip brace may be able to alter hip motion in such a way as to decrease the injury-inducing mechanisms associated with FAI.

CHAPTER FIVE

Future Research

As mention in the previous chapter, there were many limitations in this study. A future study will be conducted with a larger sample size of healthy subjects from a variety of age groups and genders will be utilized to better understand the true affects of the hip across a diverse population. In addition, more activities of daily living will be tested, such as stair climbing and sit-to-stand, as well as athletic maneuvers such as run to cuts and squats. Thus providing a full profile of the conservative treatment for active individuals. Lastly, more braces will be added to the study to find the best brace to utilize in stage two of this study. Once more data is collected a decision can be made onto which brace has the best potential use in clinical trials. Stage two of this project will be a clinical trial consisting of both healthy controls and FAI patients walking at various speeds and doing an assortment of athletic maneuvers. Additional interventional studies should be conducted to further understand the full extent of the short and long term benefits of each of the braces within an FAI patient population.

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