Using Different Surgical Procedures for Relief of Greater Trochanteric Pain Syndrome. Doctor of Philosophy (Integrative Physiology and Anatomy), July, 2014 103 pp., 4 tables, 26 figures, bibliography, 5 titles.

Greater Trochanteric Pain Syndrome (GTPS) is associated with hip pain from repeated trauma to the greater trochanter bursa. Surgical procedures cut the iliotibial tract (ITT) in order to relieve the pressure on the greater trochanter. We propose the ITT may not be the primary cause of GTPS. In this study, I hypothesize that in addition to the ITT, the tendon of the gluteus maximus (GMax) also exerts force on the greater trochanter. Force measurement tests were performed on fresh cadavers donated to the University of North Texas Health Science Center. In addition, an anatomical study of the hip was performed on partially dissected embalmed cadavers to better describe the GMax tendon and ITT insertion at the greater trochanter.

In the anatomical study, fibers from the ITT were observed comingling with the GMax tendon to insert at the gluteal tuberosity. Multiple variation of the GMax tendon were observed, some presenting with three or four tendinous slips. In this study, 157 hips were examined. 63 hips (40%) had only one tendinous slip, 57 hips (36%) had 2 tendinous slips, 34 (22%) had 3 slips, and only 3 (2%) were observed with 4 tendinous slips. One unique variation was found during the course of this study and was submitted for publication.

To measure the force exerted by the ITT at the greater trochanter, six unembalmed cadavers were used to contrast the effects of different surgical approaches used for force reduction. Force measurements were first taken for normal ITT (no cuts) and then for one of two types of ITT incisions on one hip. Next, force measurements were taken for a normal ITT and then after the GMax tendon was transected on the contralateral hip. Overall, both surgical approaches showed a strong trend in reducing force at the greater trochanter as the hip was subjected to a range of specified movements.

Even though a significant force reduction occurred with transection of the GMax tendon, making this procedure a potential new treatment for GTPS, the depth of the structure in the gluteal region might prove impractical as a practical surgical approach.

COMPARING THE CHANGE IN FORCE BETWEEN ILIOTIBIAL TRACT CUT AND GLUTEUS MAXIMUS CUT IN GREATER TROCHANTERIC PAIN SYNDROME

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Contrasting Force Reduction at the Greater Trochanter Using Different Surgical Procedures for Relief of Greater Trochanteric Pain Syndrome

Dissertation

Presented to the Graduate Council of the

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DOCTOR OF PHILOSOPHY

By

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CHAPTER I

Introduction

Originally called “trochanteric bursitis” and defined as “tenderness over the greater trochanter with the patient in the side-lying position” (Williams and Steven, 2009; Tortolani, 2002), greater trochanteric pain syndrome (GTPS) has expanded to include a number of disorders of the lateral, peritrochanteric space of the hip: greater trochanteric bursitis, snapping hip syndrome, and gluteus medius and gluteus minimus tendon tear. Trochanteric bursitis is a commonly diagnosed inflammatory condition that presents with pain localizing to the region of the greater trochanter, often with radiation down the lateral aspect of the thigh or into the buttock. Due to the continuous rubbing of the iliotibial tract (ITT) on the greater trochanter, the bursa sac surrounding the greater trochanter swells leading to tenderness and pain that travels inferiorly down the thigh, causing GTPS.

Bursae are fluid-filled sacs that provide cushioning between bony prominences and surrounding soft tissues. There are three bursae that have been consistently described around the lateral aspect of the greater trochanter: subgluteus maximus, subgluteus medius, and the gluteus minimus bursas. These bursae are believed to function as cushioning for the gluteal muscle tendons, ITT, and the tensor fascia latae muscle. Subgluteus maximus and subgluteus medius bursae are the two major bursa sacs associated with GTPS (Dunn *et al*, 2003). The subgluteus maximus bursa lies on the lateral aspect of the greater trochanter, between the tendons of the gluteus maximus and minimus tendons. It is commonly divided into 4 separate bursae: deep, superficial gluteofemoral bursa, and the deep subgluteaus maximus bursae. The secondary deep subgluteus maximus bursa is the largest and most consistent, and it is often implicated in trochanteric bursitis. It is located near the attachment of the gluteus medius, gluteus minimus, and vastus lateralis muscles.

GTPS presents most often in middle-aged patients, with females more commonly affected than males (4:1). In addition to chronic activity-related pain involving the greater trochanter, patients often report symptoms with prolonged standing, sitting with the affected leg crossed, and difficulty lying on the affected side secondary to the symptoms from the direct compression of the inflamed bursa (Tortolani, 2002). This study explores the cause of GTPS, focusing primarily on the force applied by the iliotibial tract and its accomplice, the gluteus maximus muscle, on the greater trochanter.

Painful tenderness in the greater trochanteric area is the primary symptom of greater trochanteric bursitis. Around 50% of patients experience pain radiating from the lateral aspect of the thigh to the knee (Shbeeb and Mattison, 1996; Del Buono, 2011; Gordon, 1961; Williams and Steven, 2009). Pain radiation patterns from greater trochanteric bursitis may be complicated to diagnose (Tortolani, 2002). For example, pain extending to the groin or lateral thigh may mimic lumbar disk herniation. Primary diagnosis is tenderness around the greater trochanter. Other diagnosis test include of pain on hip abduction against resistance and a positive Patric-FABERE test (pain at the extreme of rotation, abduction, adduction, or extension of the hip) (Williams and Steven, 2009).

Gluteus medius and minimus tears are secondary findings in GTPS, most commonly observed through MRIs or hip arthroscopy. Tears of the gluteus medius and minimus resemble rotator cuff muscle tears in the shoulder in that tendon injury starts with tendonitis and eventually leads to tears of the tendons at their insertion (the greater trochanter). Incidence of gluteus medius and gluteus minimus muscle tears is highest in older populations, and it is more prevalent in females than in males (Strauss *et al*, 2010). Primary symptoms in patients with gluteus medius and gluteus minimus muscle tears are lateral hip pain, tenderness, palpation on the greater trochanter, and weakness of hip abduction. In a physical examination, patients may show pain and weakness with active, resisted abduction, extension, and external rotation with the hip flexed to 90 degrees (Strauss *et al*, 2010).

Coxa saltans (snapping hip syndrome) is an audible and painful snapping of the hip during activities that require repetitive flexion, extension, and abduction (Strauss *et al*, 2010; Allen and Cope, 1995). The external snapping of the hip is caused by repetitive gliding of the iliotibial tract (ITT) and anterior border of the gluteus maximus overlying the greater trochanter during hip flexion activities. People who present with external coxa saltans tend to be in their late teenage years or early twenties and frequently have an athletic lifestyle. Diagnosis of external coxa saltans is typically based on patient history. Patients may describe a painful, snapping sensation that is localized around the greater trochanter. In a physical examination, the patient will lay on their unaffected side and then flex their affected hip while the examiner will palpate the greater trochanter, feeling the snapping of the ITT (Strauss, 2010). Repair of snapping hip syndrome is often accomplished with a technique call iliotibial tract release wherein two incisions are made in the ITT directly over the greater trochanter. The longer of the two incisions is a vertical incision about 2-3 cm in length, the shorter is a transverse incision about 1-2 cm in length (Ilizalitturi *et al*, 2006).

Clinical studies have shown that GTPS is linked to other conditions. The prevalence of GTPS in adults with musculoskeletal lower back pain is between 20%-35% (Williams and

Steven, 2009; Segal et al, 2007). In a large, multicenter, cross-sectional study involving 3026 middle-age to elderly adults, GTPS was found in 17.6% of people, with higher incidence in women and patients with co-occurring low back pain, osteoarthritis, IT band tenderness, and obesity. In an observational study, 91.6% of patients diagnosed with trochanteric bursitis (GTPS) had other associated conditions: peripheral osteoarthritis, rheumatoid arthritis, and lumbosacral (lower back) osteoarthritis (Strauss 2010, Williams and Steven, 2009).

The greater trochanter is a large, lateral bony mass that projects superiorly and posteriorly where the femoral neck joins the shaft of the femur. It provides attachment and leverage for abductor and rotator muscles of the thigh. The fascia lata is the deep fascia of the thigh that wraps around the thigh muscles. Laterally the fasciae latae thickens and is strengthened by additional reinforcing longitudinal fibers to form the iliotibial tract (ITT). This broad band is the shared aponeurosis of the tensor fasciae latae and gluteus maximus muscles, and it extends from the iliac tubercle to the anteriolateral (Gerdey's) tubercle of the tibia.

The gluteus maximus muscle is the largest and most powerful muscle in the gluteal region of the body. It is the most superficial of the three gluteal muscles, covering all of the others except for a small part of the gluteus medius muscle. The gluteus maximus slopes inferiolaterally at a 45º angle from the pelvis to the gluteal tuberosity (Moore *et al*, 2010). The superior two-thirds (approximately) of the fibers of the gluteus maximus muscle insert laterally into the ITT at its proximal end near the mid-to-inferior part of the tensor fasciae latae muscle. The remaining deep (inferior) fibers of the gluteus maximus insert into the gluteal tuberosity of the proximal femur. The deep fibers form a significant insertion complex at the gluteal tuberosity that is not well defined in the current anatomical literature.

A major objective of this study was to examine these deep fibers in detail, and develop a better understanding of the tendinous insertion to which they contribute at the gluteal tuberosity. Another major objective of the study was to determine if the ITT contributes to this tendinous complex, and how the collaboration of the two structures (gluteus maximus and iliotibial tract) might structurally contribute to GTPS. During locomotion, the iliotibial tract rubs across the greater trochanter, and its action is influenced by the tensor faccia lata and the gluteus maximus muscle (Moore *et al*, 2010; Drake *et al*, 2010). Working with the gluteus maximus muscle, the iliotibial tract stabilizes the hip joint by preventing lateral displacement of the proximal end of the femur (Drake *et al*, 2010).

Most cases of GTPS are resolved through conservative measures. These treatments consist of ice, weight loss, physical therapy, corticosteroid injections, and behavior modification that aim to improve flexibility and muscle strength. In an observational study on corticosteroid injection, 77% of people participating had relief after one week, and 61% of patients had relief after six months (Del Buono, 2011). A systematic review on the treatments of GTPS found that traditional, non-operative therapies, such as supervised stretching and strengthening, physical therapy modalities, and corticosteroid and local anesthetic injections to the trochanteric area, have been reported to be at least transiently helpful. There have been a number of recurrences of symptoms and incomplete relief has been commonly observed when using corticosteroid injections. One study showed improved relief for five patients when doing a bursectomy (Del Buono, 2011). However, another study indicated the bursectomy procedure was disappointing, because five recurrences of pain were seen from 12 patient hips (Del Buono, 2011). In conclusion, the systematic review suggested that future research trials should focus on the application and effectiveness of various conservative modalities for management of GTPS. (Del Buono, 2011)

There are two types of surgical incisions that are used to relieve the pressure around the greater trochanter for treatment of GTPS. The first is the Z-plasty technique which is a Z-shaped incision of the ITT to relieve the tightness of the gluteus maximus muscle (Brignall and Stainsby, 1991). The ITT release technique (T-cut) is an endoscopic procedure employed for greater trochanteric bursectomies and is commonly used to treat snapping hip syndrome. ITT release is a cross-shaped incisions, one longer vertical (2-3cm) and a shorter transverse (1-2cm) (Ilizaliturri *et al*, 1006). Studies of both surgical techniques have reported relief of pain on the greater trochanter (Nam et al, 2009; Ilizaliturri et al, 2006). However, there is a lack of studies that evaluate how much pressure is relieved around the greater trochanter. I evaluated the amount of pressure reduction induced by both the Z-plasty and the ITT release techniques in this study, and will be referred to later in this document as the Z-cut and T-cut, respectively.

In December of 2010, hips of 12 embalmed cadavers (8 males and 4 females) were examined. Observational studies showed that tension around the greater trochanter originated from multiple sources. First, tightness of the ITT over the greater trochanter was observed originating from the ITT that extended from the iliac crest to the insertion of the gluteus maximus muscle near the gluteal tuberosity (average distance of 21.3 cm). The tension was not alleviated even when the ITT was transected at the mid-thigh level. An incision was made between the ITT and the tensor fasciae latae muscle revealing a second structure contributing to tightness over the greater trochanter. Upon further observation, it was determined to be the tendon of the gluteus maximus inserting at the gluteal tuberosity slightly inferior to the greater trochanter (Figure 1). Figure 2 shows the gluteus maximus tendon of the left hip from a medial view with the hip completely detached. Note the large single tendon (oval) attaching directly to the gluteal tuberosity of the femur.

In many of the initially dissected hips, and as the figure suggests, multiple tendinous slips from what first appeared to be only the gluteus maximus tendon were often observed. After further dissection of the hip seen in Figure 1, multiple tendinous fibers from both the ITT and the gluteus maximus were observed inserting into the gluteal tuberosity (oval). Based on direction of the striated fibers, two of the fibers appeared to belong to the gluteus maximus muscle, while the most superior fiber appeared to originate from the ITT. This observation, along with the tension felt between the ITT and the greater trochanter, created the initial interest in this project to further investigate the relationship of these structures to GTPS.

Research Goals

The goal of this project was to gain a better understanding of the anatomical relationships of the structures associated with GTPS, and to investigate what is the primary cause of GTPS. It is hypothesized that in addition to the force exerted on the greater trochanter by the ITT, the tendon of the gluteus maximus muscle (GMax) also exerts force on the greater trochanter. A force measurement experiment was designed to see how much force was exerted on the greater trochanter with an intact ITT compared to a Z-cut or T-cut of the ITT. In addition, the intact ITT was compared to GMax tendon transected from the gluteal tuberosity called a GMax-cut. The goal was achieved by the following aims:

1) *Describe the anatomical relationships of the ITT, the GMax muscle, the gluteal tuberosity, and the greater trochanter by performing a thorough dissection of the hip joint.* Variability of the GMax tendon, its insertion pattern, and number of tendinous slips, as well as the contribution from ITT fibers that converge into the GMax tendon,

were observed and documented. This was an anatomical observation study that provides a better understanding as to how the GMax and the ITT combine to insert into the greater tuberosity.

2) *Measure the force exerted on the greater trochanter during a range of different thigh motions.* This part of the study measured the force exerted by the ITT when the Z-cut and T-cut incisions were made on the ITT tract versus when the GMax tendon was transected from the gluteal tuberosity. The aim was to determine whether the ITT or the GMax had a greater influence on force applied to the greater trochanter during a range of hip motions. On one hip, the force exerted on the greater trochanter by an intact ITT was compared with the force exerted subsequent to either a Z-cut or T-cut of the ITT. On the contralateral hip of the same cadaver, force exerted on the greater trochanter was compared between the control state (intact ITT) versus GMax cut. Finally, the difference in force change between the ITT cuts and GMax-cut were compared.

Figure 1. Anatomical dissection of the left hip of a male cadaver. The ITT tract is reflected medically exposing the tendon to the gluteus maximus muscle (oval). Posterior is towards the top of the image, superior to the left.

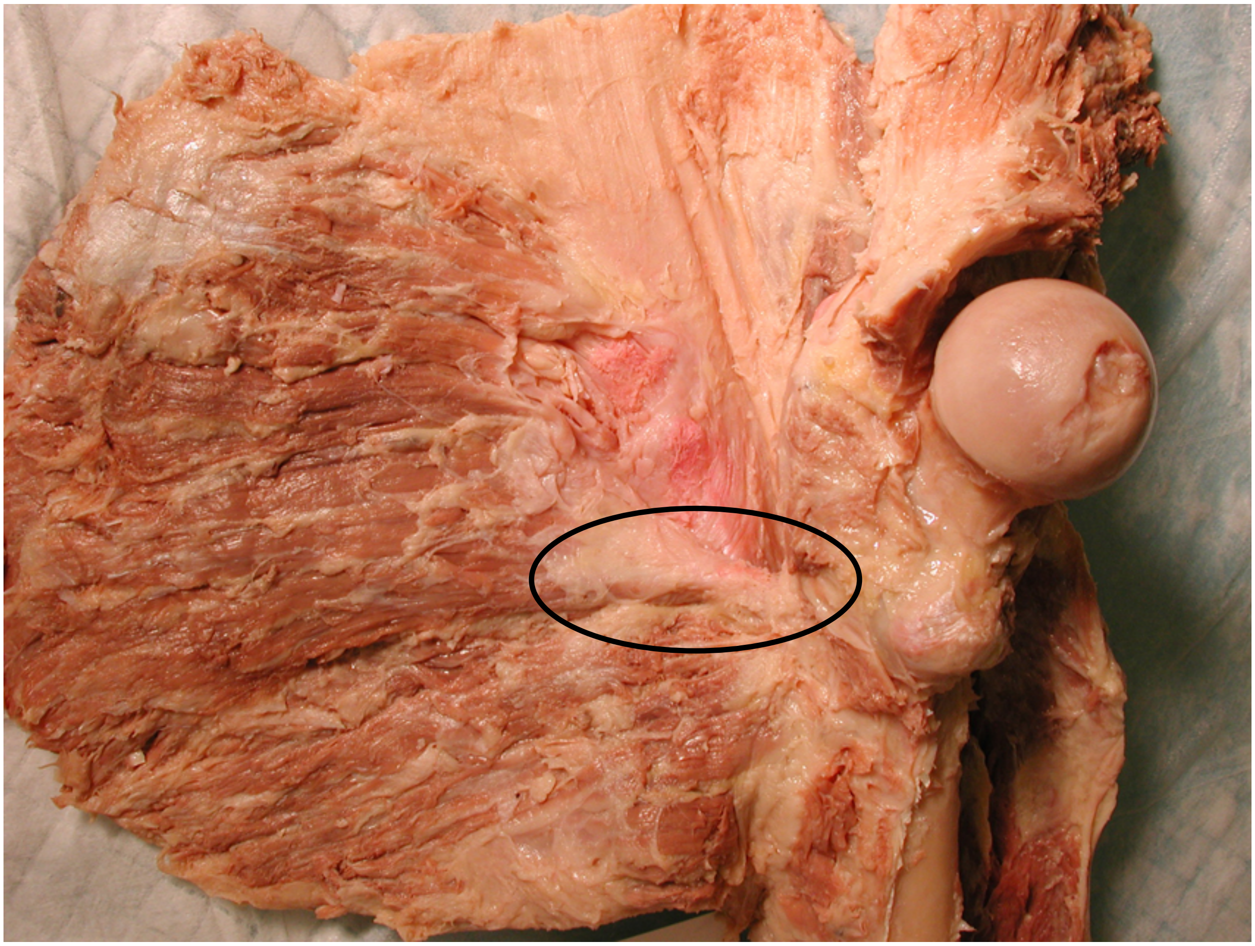

Figure 2. Anatomical dissection of the left hip of a male cadaver. The large tendon from the gluteus maximus muscle can be seen inserting into the gluteal tuberosity of the proximal femur (oval).

CHAPTER II

The following manuscript was published in the ***International Journal of Anatomical Variations,*** 2014. 7: 1000–1001.

A Variant Accessory Muscle of the Gluteus Maximus

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Summary

Routine dissection of the gluteal region revealed an accessory muscle originating from the deep, inferior fibers of the gluteus maximus muscle. The described muscle was surrounded by a separate facial sheath and contained fibers that converged into a tendon with origins from both the gluteus maximus muscle and the iliotibial tract. This tendon inserted on the proximal femur lateral to the intertrochanteric crest, slightly superior to the superior border of the gluteal tuberosity. Typically, the inferior fibers of the gluteus maximus muscle insert into the gluteal tuberosity. This variant accessory muscle of the gluteus maximus, with a separate muscle belly and tendinous insertion has not been previously described in the literature regarding the anatomy of the gluteal region.

Introduction

The gluteus maximus muscle is the largest and most powerful muscle in the gluteal region of the body. It is the most superficial of the three gluteal muscles, covering all of the others except for a small part of the gluteus medius muscle. The gluteus maximus slopes inferiolaterally at a 45º angle from the pelvis to the gluteal tuberosity [1]. The superior two-thirds (approximately) of the fibers of the gluteus maximus muscle insert laterally into the iliotibial tract at its proximal end near the mid-to-inferior part of the tensor fasciae latae muscle. The remaining, inferior fibers of the gluteus maximus insert into the gluteal tuberosity of the proximal femur. The iliotibial tract is the lateral thickening of the fasciae latae, forming a longitudinal band that passes over the greater trochanter and extends from the tubercle of the iliac crest to Gerdy's tubercle on the lateral side of the proximal tibia. The iliotibial tract serves as an attachment site for the gluteus maximus and tensor fascia latae muscles. With the gluteus maximus muscle, the iliotibial tract stabilizes the hip joint by preventing lateral displacement of the proximal end of the femur [2].

Case Report

As a part of a series of dissections with the intent to improve the anatomical understanding of Greater Trochanteric Pain Syndrome (GTPS), we observed a variant accessory muscle originating from the gluteus maximus muscle in the right hip of a 79-year-old, embalmed, female cadaver. Figure 1 shows the image of the cadaveric right hip after initial reflection of the gluteus maximus muscle. This accessory muscle contained a distinct muscle body and tendon bound in a separate fascial sheath (Figure 1, arrowheads). A more detailed dissection of the same hip clearly showed the variant muscle body arising from the inferior fibers of the gluteus maximus muscle (Figure 2, arrows). The variant muscle's tendon (Figure 2, asterisk) inserted on the proximal femur lateral to the intertrochanteric crest and superior to the upper boundary of the gluteal tuberosity. Additionally, we observed a small tendon that arose from the iliotibial tract and then inserted into the superior aspect of the variant muscle's tendon (Fig. 2, arrowhead). The remaining deep fibers of the gluteus maximus muscle appeared to insert normally into the iliotibial tract near the tensor fasciae latae muscle and on the gluteal tuberosity of the proximal femur (Figures 1 and 2, dashed lines).

Discussion

Greater trochanteric bursitis is a commonly diagnosed problem often associated with Greater Trochanteric Pain Syndrome (GTPS). This syndrome is usually the result of prolonged rubbing of the iliotibial tract on the greater trochanter, irritating and inflaming the bursa sac surrounding the greater trochanter. Common sequelae include swelling, tenderness, and pain that radiates from the lateral hip that often travels inferiorly down the thigh [3]. The gluteus maximus muscle adjoins the iliotibial tract, suggesting that it, too, may be involved in GTPS. While undertaking an anatomical study of possible causes of GTPS, we observed a specimen that exhibited a variation in the deep, inferior fibers of the gluteus maximus muscle. The variant muscle's tendon inserted into the proximal femur lateral to the intertrochanteric crest, superior to the deep, inferior fibers of the gluteus maximus muscle that normally insert into the gluteal tuberosity of the femur. This unusual insertion point for the variant tendon could have potentially caused GTPS-like symptoms in this individual.

The gluteus maximus muscle is a large muscle that has variable insertion sites for its numerous muscle fibers, with the superior part of the gluteus maximus inserting into the iliotibial tract [4]. In the hip dissections we observed (n=77), fibers of the gluteus maximus muscle merged with fibers from the iliotibial tract, primarily in a lateral and posterior position to the joint capsule. The deeper fibers of the inferior part of the gluteus maximus muscle attached to the gluteal tuberosity of the femur. The left hip from this cadaver was the only specimen observed with an accessory muscle originating from the main body of the gluteus maximus muscle. We have not found this variant described previously in the literature and believe it to be a unique anatomical variation.

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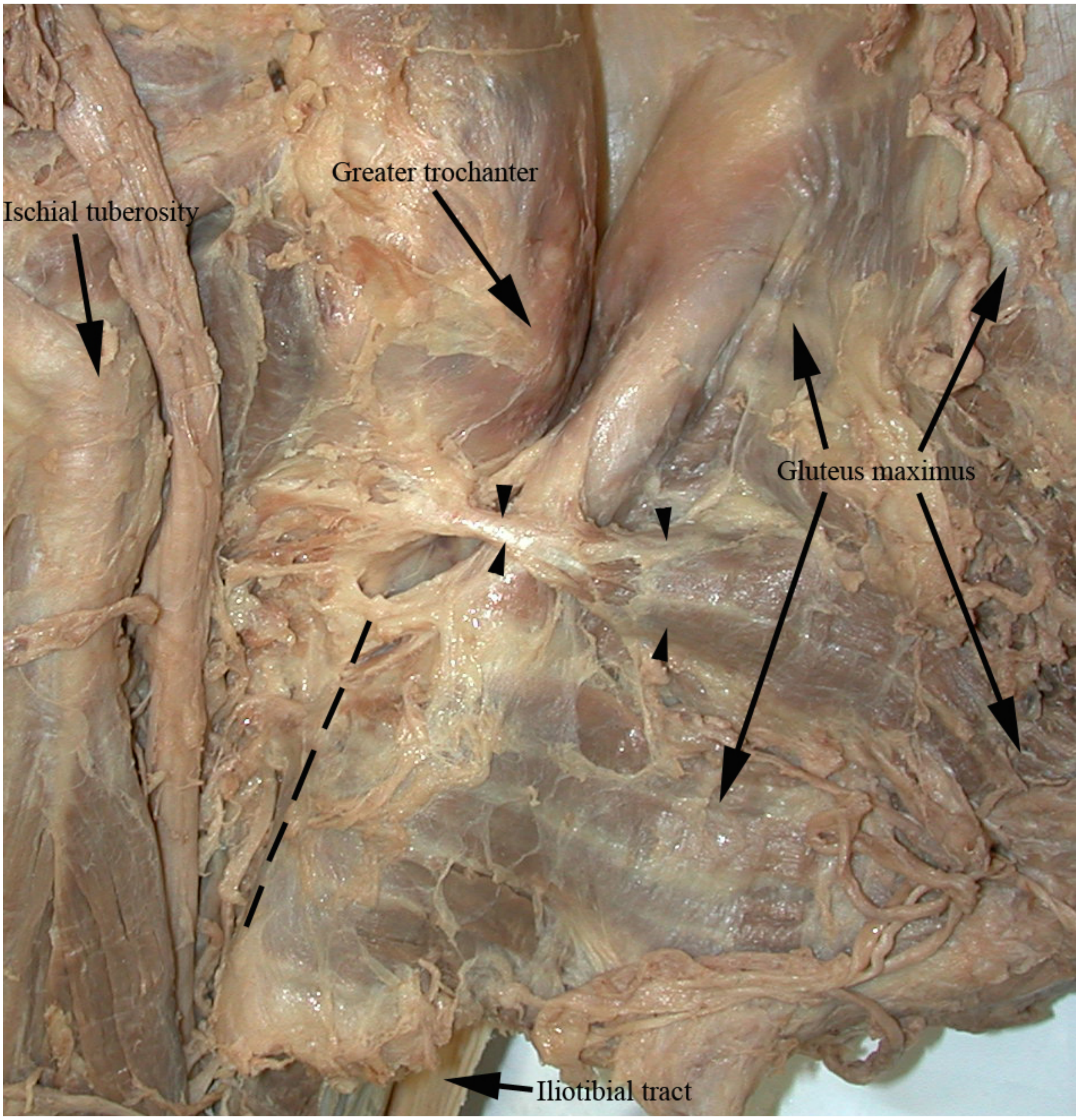

Figure 1. Posterior view of the right hip as viewed when the gluteus maximus muscle was first reflected. Note the separate facial sheath surrounding the accessory muscle and tendon (arrowheads). Lower fibers from the gluteus maximus muscle insert below the accessory muscle's tendon at the gluteal tuberosity (dashed lines). Superior is the top of the image; medial to the left

Figure 2. Posterior view of the detached right hip showing the gluteus maximus muscle reflected. This is the same hip as shown in Figure 1, but with a more detailed dissection. The variant accessory muscle body (arrows) can be clearly seen with its tendon (asterisk) inserting into the proximal femur, lateral to the intertrochanteric crest, and superior to the gluteal tuberosity (dashed line). Fibers from the iliotibial band are shown inserting into the accessory muscle's tendon (arrowhead).

CHAPTER III

The following will be submitted to *Clinical Anatomy*

Title: An anatomical study of the tendinous insertion of gluteus maximus into the gluteal tuberosity.

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Abbreviated Title: Tendinous insertion of gluteus maximus

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An anatomical study of the tendinous insertion of gluteus maximus into the gluteal tuberosity.

Abstract

Introduction. The gluteus maximus (GMax) muscle is organized into two layers: superficial and deep. The deep fibers of the muscle attach to the gluteal tuberosity and are the major focus of this study. The tendinous attachment of the deep GMax fibers to the gluteal tuberosity is vaguely described in the anatomical literature. This study describes a variable tendon complex from the deep fibers of the GMax muscle with contributions from the iliotibial tract (ITT). **Materials and Methods.** Overall, 157 hips from 79 cadavers were used for the study. Sex and number of tendinous slips from the GMax at the insertion on the gluteal tuberosity were recorded. Hips were excluded from the study if the muscle belly of the GMax was cut from the ITT, if surgery had been performed, if the tendon was calcified, or if the GMax muscle belly was completely separated from its tendon. A chi-square test was performed to test for differences between the sexes. **Results**. Sixty-three hips (40%) had a single tendon, and the remaining hips (n=94) had multiple (2 or more) tendinous slips from the GMax inserting into the gluteal tuberosity. Fibers from the ITT were observed forming part of the tendon complex from the deep GMax muscle fibers in most cases. **Conclusions.** This study improves our understanding of the GMax tendon and the ITT regarding their relationship to the gluteal tuberosity. The deep muscle fibers from the GMax form a strong, complex tendinous structure that has clear contributions from the ITT.

Key Words: Gluteus maximus; gluteal tuberosity; iliotibial tract; greater trochanter pain syndrome

Introduction

As part of a study examining ways to improve treatment of Greater Trochanteric Pain Syndrome (GTPS), the insertions site of the gluteus maximus (GMax) muscle at the gluteal tuberosity was observed. GTPS was originally called "trochanteric bursitis" and defined as "tenderness over the greater trochanter with the patient in the side-lying position" (Schapira, 1986). GTPS is a commonly diagnosed inflammatory condition that presents with pain localizing to the region of the greater trochanter, often radiating inferiorly along the lateral aspect of the thigh or into the buttock. GTPS is caused by the continuous rubbing of the iliotibial tract (ITT) on the greater trochanter, leading to swelling of the bursa sac surrounding the greater trochanter and tenderness and pain that travels inferiorly along the thigh. Due to the close proximity of the greater trochanter to the insertion of both the ITT and GMax at the gluteal tuberosity, more detailed reporting of their anatomical relationship than has previously been documented might provide insight into future development of another approach for treatment of GTPS.

The GMax is the largest muscle of the lower limb (Ward et al, 2009), as well as the largest and most superficial muscle in the gluteal region of the human body. This muscle is organized into two layers: superficial and deep. The deep fibers of the inferior part of the muscle attach to the gluteal tuberosity and are the major focus of this study. The fibers of the superficial part of the GMax represent about 80% of the muscle's total mass and insert into the ITT (Reiman et al, 2012). The ITT is a thickening of the fascia lata into a longitudinal band on the lateral thigh. It originates from the iliotuberculum of the iliac crest and inserts into Gerdy's tubercle on the superolateral tibia. Other insertion sites for the ITT include the linea aspera via the lateral intramuscular septum, lateral epicondyle, and the patella (Binbaum *et al*, 2004; Vieira *et al*, 2007). A biomechanical study of the ITT reported that it passes over the greater trochanter without developing a fixation to the bone (Binbaum *et al,* 2004). In addition, the ITT serves as an attachment site for the GMax and tensor fasciae latae muscles, and their common association helps to stabilize the hip joint by preventing lateral displacement of the proximal end of the femur (Drake et al, 2010).

Previous descriptions of the GMax and the ITT in the anatomical literature are mostly consistent. Most textbooks describe the superficial fibers from GMax inserting into the ITT and the deeper inferior fibers inserting at the gluteal tuberosity of the proximal femur without mention of a tendinous structure (Romanes, 1976; Hollinshead and Rosse, 1985; Snell, 1995; Standring, 2008; Moore *et al,* 2010; Drake *et al*, 2010). Predominantly, the deep fibers are described and drawn as an elongated bundle of muscle fibers attaching directly to bone at the gluteal tuberosity. Rarely is the word "tendon" used in the anatomical literature to describe the muscle attachment at this site. In two research studies from the 1970s, Stern (1970) and Janecki (1977) described the deep fibers as a "tendon" and "tendinous insertion", respectively; however, that description is not used widely in more recent anatomical literature. A few anatomical illustrations show some tendinous fibers attaching to the gluteal tuberosity (Moore *et al,* 2010; Drake *et al*, 2010), but most represent the bulk of this attachment site with muscle fibers attaching directly to the femur. Upon closer inspection of the actual insertion site at the gluteal tuberosity, a more variable and complex anatomical structure is revealed. When dissected carefully, the upper portion of the deep fibers from the GMax form a strong, thickened tendinous band prevalent in most cadavers described here. We describe the morphological variation of this structure, including description of which strutures contribute to its formation. We hypothesize that the tendon receives contributing fibers from both the GMax and ITT, and that this arrangement has not been described previously in the literature. This band is often observed to have single or double insertion slips, and may sometimes have three or more slips. This tendon is formed primarily from the GMax, but as this study demonstrates, almost always has contributing fibers from the ITT.

Materials and Methods

To better understand the anatomical relationship associated with GTPS, the insertion site of the GMax muscle at the gluteal tuberosity was exposed. This study utilized 79 partially dissected, embalmed cadavers that were donated through the Willed Body Program at the University of North Texas Health Science Center.

The majority of cadavers were originally dissected by first year medical students attending the Texas College of Osteopathic Medicine from 2011-2013; however, a few were dissected by graduate students and faculty. During these dissections, the skin in the thigh and gluteal region of the cadavers was removed. In most of the cadavers, the GMax muscle was detached from the sacrum, coccyx and underlying structures and reflected laterally. For study purposes, the ITT was cut from the origin (ilium) and reflected to gain access to the GMax tendon where it inserted into the gluteal tuberosity. The fat in the area around the greater trochanter was cleaned until the tendon of the GMax was revealed. Afterwards, the tendons were examined for contributing ITT fibers and the number of tendinous slips inserting into the femur.

Hips from cadavers were excluded from the study if the muscle belly of the GMax was cut off from the ITT, if hip surgery had been performed, if the tendon was calcified, or if the gluteus maximus muscle belly was completely separated from its tendon. Overall, 157 hips from 79 cadavers were studied. Sex and number of tendinous slips inserting into the gluteal tuberosity were recorded for all dissected hips. A chi-square test was performed to test for differences between the sexes.

Results

For this study, 157 hips were examined for configuration of the GMax tendon; 79 male and 78 females hips total (Table 1). Of those observed, 63 hips (40%) had a single tendon (31 found on the right, 32 on the left). The remaining hips (n=94) had multiple (2 or more) tendinous slips where the GMax inserted into the gluteal tuberosity. Fifty-seven (57) hips had two tendinous slips (28 on the right, 29 on the left); 34 hips had three tendinous slips (17 observed equally on both sides), and 3 were observed with four or more tendinous slips (1 on the right, 2 on the left). No significant difference was found in the number of tendinous slips with regard to sex in the study ($X^2 = 0.009$; df = 1; p = 0.923).

Figure 1A shows a common example of a single tendon from the GMax inserting into the gluteal tuberosity. This figure is a posterior view of the left hip from an 83-year-old male cadaver with both the GMax and the ITT clearly shown in relation to the greater trochanter. Figure 1B is an anterior view of the same hip seen in 1A, showing a large, single tendon inserting into the gluteal tuberosity of the femur. The tensor fasciae latae (TFL) muscle can be seen anterior to the ITT in this image. Figure 1C is a close-up view of the tendon seen in 1B. At the arrowheads, note the comingling fibers of both the GMax and the ITT to form the single tendon that inserts at the gluteal tuberosity.

Figure 2A is a posterior view of the right hip from another 83-year old male cadaver showing a double tendinous slip of the deep GMax and ITT fibers inserting into the gluteal tuberosity. Another example of a double slip tendon is seen in Figure 2B on the left hip of a 66-year old female cadaver. Note the large, upper portion with contributing fibers from the ITT. There was great morphological variation between hips with multiple tendinous slips, as exemplified in the differences seen between the specimens in Figures 2A and 2B (both with double tendons).

Figure 3 shows a typical triple tendon in a lateral view on a male cadaver (age unkown) with the ITT reflected medially. Other unique insertion configurations were observed over the course of the study. In a recent manuscript, Taylor *et al* (2014) reported a triple tendinous slip with an unusual variation of the GMax muscle. Originating from the inferior and deep muscle fibers of the GMax, a unique accessory muscle with a separate tendon was observed in a 79-year old female cadaver, which inserted at the intertrochanteric crest, superior to the normal insertion of the GMax at the gluteal tuberosity.

In the current study, observations showed comingling fibers from both the GMax and the ITT forming the tendon that inserts at the gluteal tuberosity. In most hips observed, the ITT fibers inserted into the superior portion of the tendon, with fibers from the GMax inserting inferiorly to form the middle and inferior portion of the tendon. If double tendinous slips were observed, fibers from the ITT could often be seen contributing to both, while fibers from the GMax contributed only to inferior tendinous slip. However, it was not obvious whether fibers from the ITT contributed to all tendinous slips when three or four were observed. A more detailed study of individual fibers is needed to determine percent contribution, fiber direction, and fiber location from the GMax muscle and the ITT to their insertion site at the gluteal tuberosity.

Discussion

The GMax muscle belly runs obliquely from the pelvis to the femur. The majority of muscle fibers of the GMax muscle insert into the ITT. Some deep fibers of the inferior part of the muscle attach to the gluteal tuberosity of the femur (Romanes, 1976; Hollinshead and Rosse, 1985; Snell, 1995; Standring, 2008; Moore *et al,* 2010; Drake *et al*, 2010). As observed in this study, some of these fibers form a tendon that often separates into multiple tendinous slips at the inferior border of the greater trochanter where they insert into the gluteal tuberosity. Direct compression of the inflamed bursa sac at the greater trochanter has been linked to pain associated with GTPS (Strauss *et al,* 2010). Identification of the source of this force (e.g. tendinous slips from the GMax and ITT) could be beneficial for exploration of possible novel treatments. A more detailed evaluation of the fiber contribution, direction, and biomechanics could potentially contribute to investigations which propose new treatment modalities for alleviation of hip pain associated with GTPS.

Atlas and textbook drawings of the GMax primarily show an elongated, vertical mass of the deep muscle fibers inserting into the gluteal tuberosity, with little reference to the presence of a large tendon as we describe here. We propose a new description of the GMax tendon in which the deep GMax fibers thicken superiorly to form a large tendon that inserts into the upper part of the gluteal tuberosity. Only the inferior portion of these deep muscle fibers attach directly to bone at the gluteal tuberosity (as depicted in most anatomical illustrations for all GMax fibers). In addition, the ITT has fibers that comingle with fibers from the GMax tendon prior to insertion on the gluteal tuberosity. The anatomical literature consistently mentions the ITT inserting onto the tibia; however, there is no reference to fibers from the ITT contributing to the GMax tendon that inserts at the gluteal tuberosity of the femur. Additionally, representative drawings in the anatomical literature of the tendon showing the comingling of these fibers are lacking.

This study improves our understanding of the tendon formed by the deep fibers of the GMax, and its relationship to the ITT regarding their insertions on the gluteal tuberosity. Anatomical literature states the GMax muscle inserts into the gluteal tuberosity; however, there is very little reference to the tendon at the insertion site and its variability. In addition, there is a lack of understanding with regard to the ITT’s contribution to the GMax tendon where it inserts into the gluteal tuberosity. Future studies are warranted to determine the percentage of fibers from the ITT that comingle with deep fibers of the GMax to form the tendon attaching at the gluteal tuberosity.

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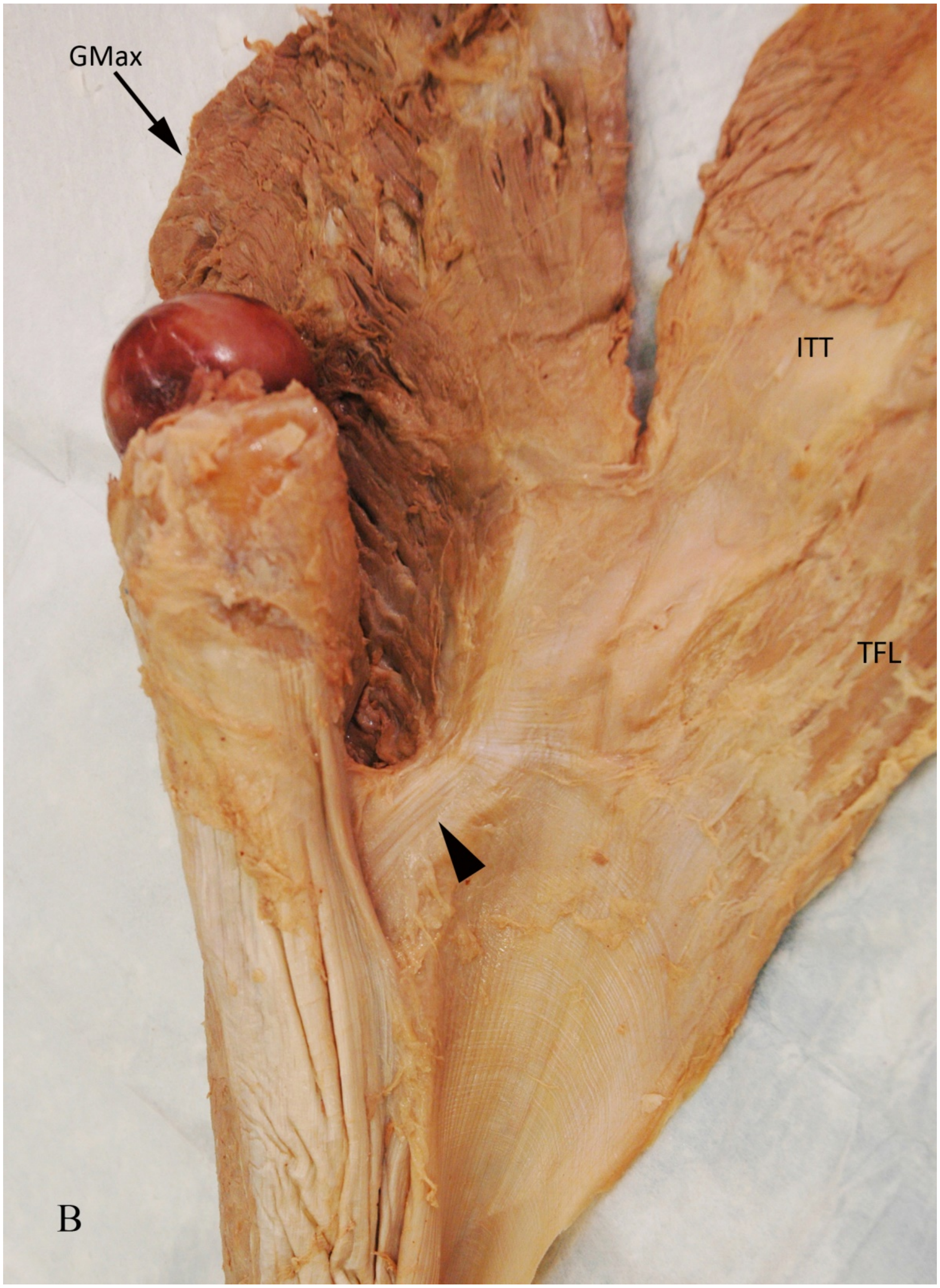
GMax	Number of Tendinous Slips								
	Single (1 tendon)		Double (2 slips)		Triple (3 slips)		4 or more (4 or more slips)		
	Left	Right	Left	Right	Left	Right	Left	Right	Total
Male	17	15	16	13	9	8	0	1	79
Female	15	16	13	15	8	9	2	0	78
Total	32	31	29	28	17	17	2	1	157

Table 1. Number of hips dissected indicating the number of tendinous slips of the GMax observed as it inserts into the gluteal tuberosity. Each hip was categorized as left/right and male/female.

Figure 1A. Posterior view of left hip of an 83-year old male cadaver with a single tendon inserting into the gluteal tuberosity. GMax = gluteus maximus muscle, ITT = iliotibial tract.


GMax
ITT
A

Figure 1B. Anterior view of the same hip shown in 1A. Note the strong, single tendinous slip (arrrowhead). TFL = tensor fasciae latae muscle.


GMax
ITT
TFL
B

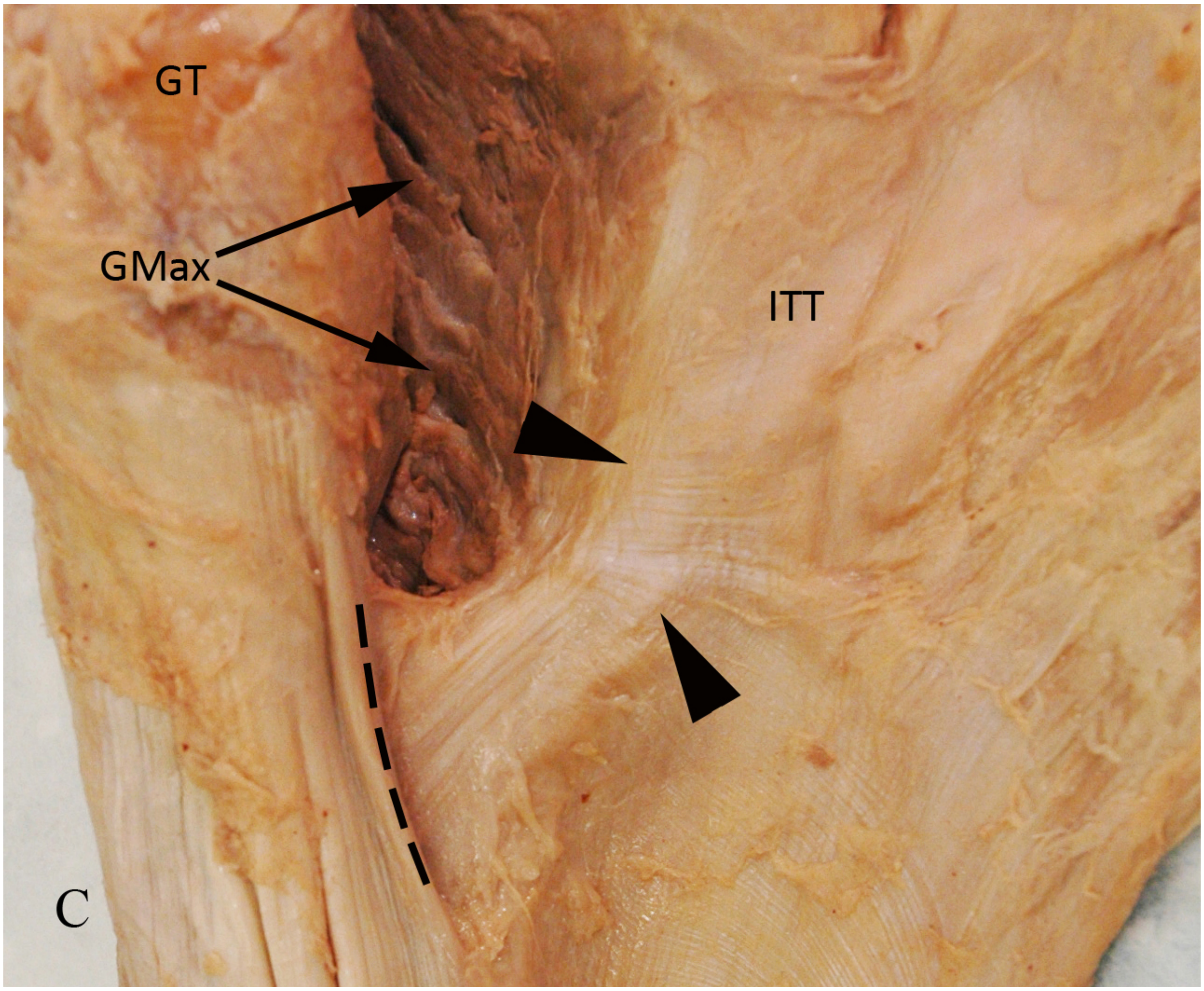


Figure 1C. Enlarged image of 1B showing the converging fibers (at arrowheads) of the gluteus maximus (GMax) muscle and the iliotibial tract (ITT) as they both insert into the gluteal tuberosity (hashed lines). GT = greater trochanter.

Figure 2A. Right hip of an 83-year old male cadaver showing two tendinous slips from the GMax and ITT (arrows) inserting on the gluteal tuberosity. Fibers from the superior tendionus slip are primarily from the ITT, while the inferior tendionous slip fibers are from the gluteus maximus.

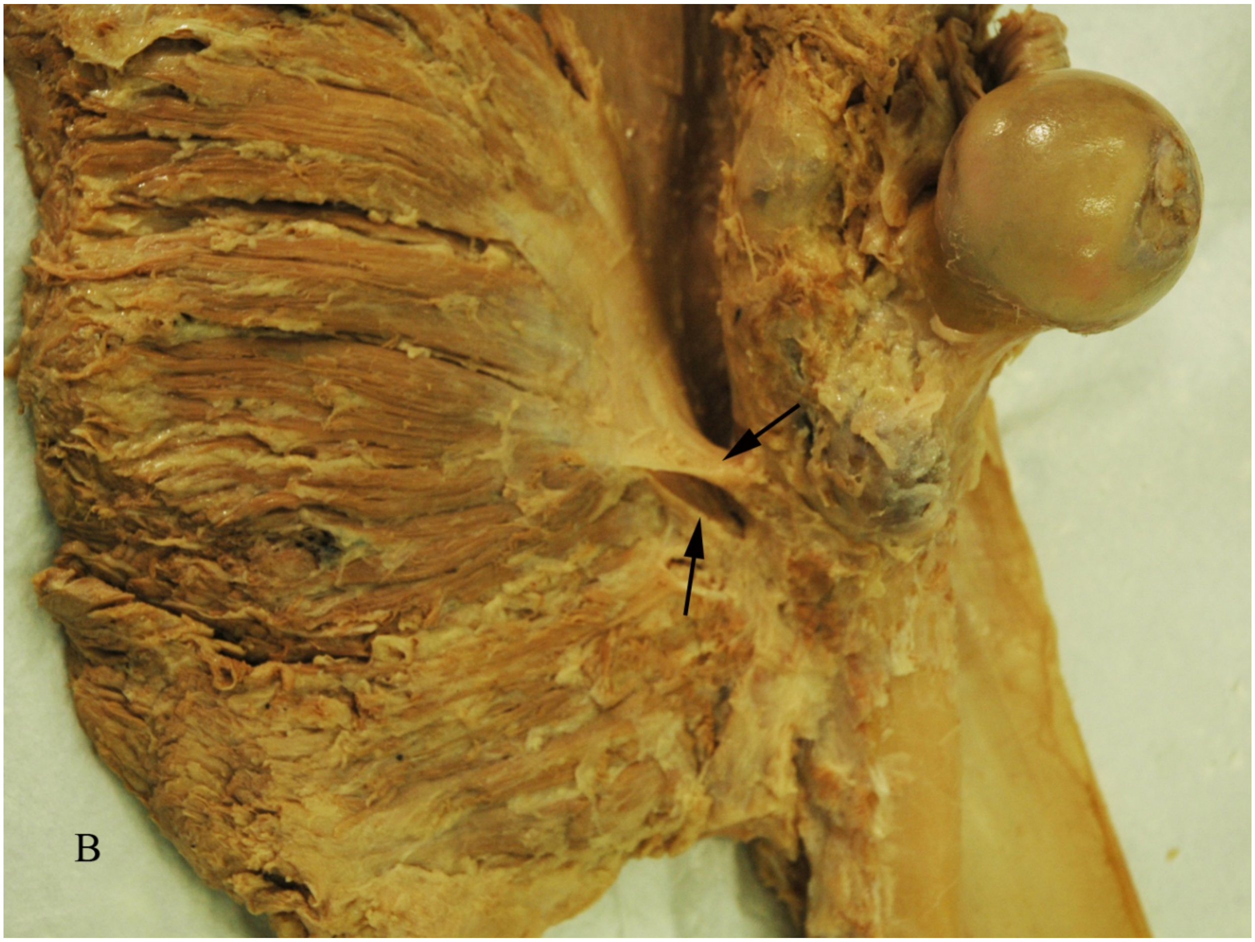


Figure 2B. Another example of two tendinous slips of the gluteus maximus (arrows) from the left hip of a 66-year old female cadaver shown inserting into the gluteal tuberosity. The superior slip has contributing fibers from the ITT.

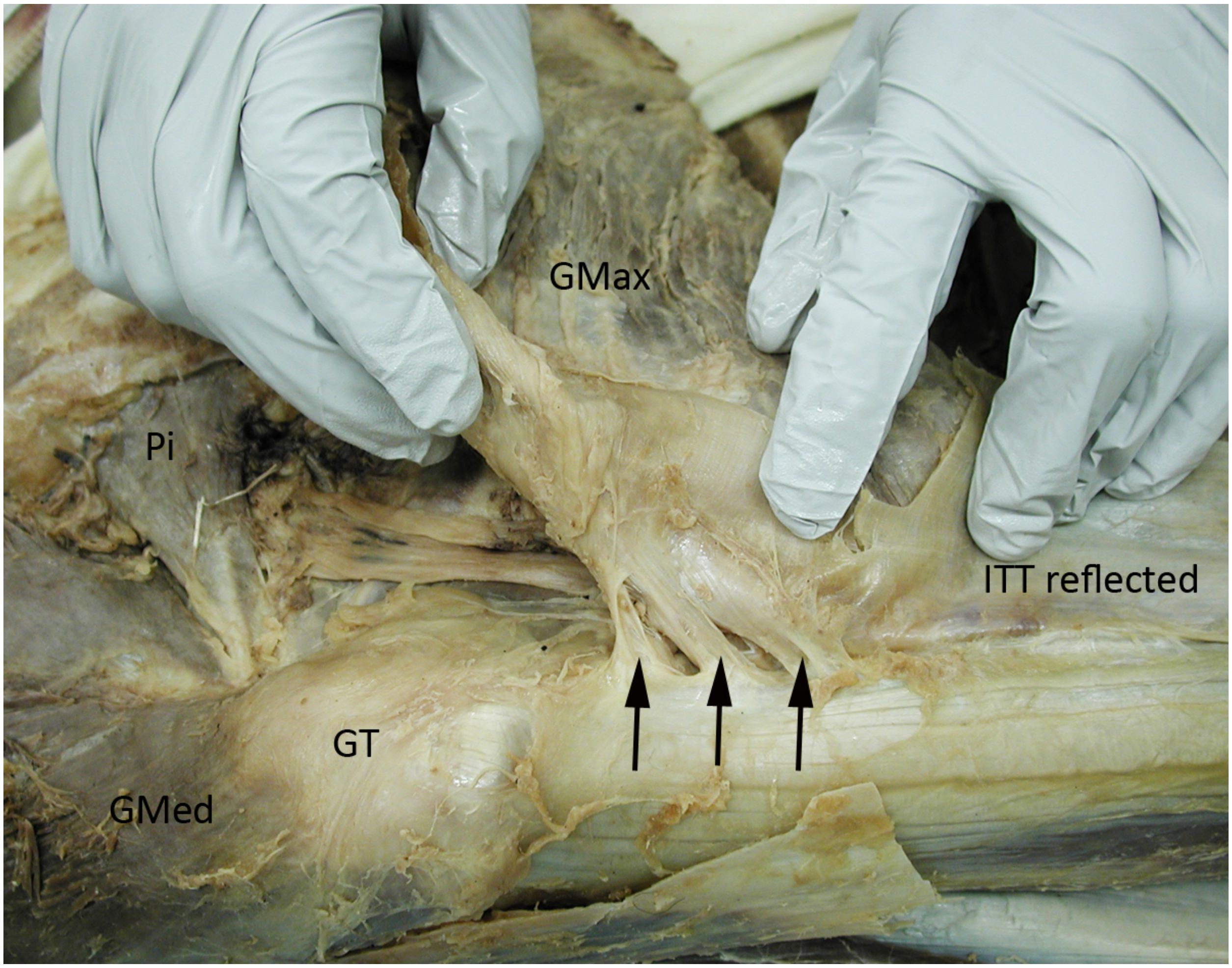


Figure 3. Lateral view of the left hip of a male cadaver (age unknown) showing a clear example of a triple set of slips from the GMax and the ITT inserting into the gluteal tuberosity inferior to the greather trochanter (GT). The ITT has been cut and reflected medially to reveal these tendinous slips. GMed = Gluteus medius muscle, Pi = Piriformis muscle.

CHAPTER IV

Contrasting Force Reduction at the Greater Trochanter Using Different Surgical Procedures for Relief of Greater Trochanteric Pain Syndrome

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Introduction

Greater Trochanteric Pain Syndrome (GTPS) is a commonly diagnosed inflammatory condition that presents with pain localized to the region of the greater trochanter, which radiates inferiorly along the lateral aspect of the thigh or into the buttock region. Originally called "trochanteric bursitis" and defined as "tenderness over the greater trochanter with the patient in the side-lying position," GTPS has expanded to include a number of disorders of the lateral, peritrochanteric space of the hip: greater trochanteric bursitis, snap hip syndrome, and gluteus medius and gluteus minimus tendon tear (Strauss *et al*, 2010). Pain related to GTPS is due to the continuous rubbing of the iliotibial tract (ITT) on the greater trochanter, causing the bursa sac surrounding the greater trochanter to swell, leading to tenderness and pain that travels inferiorly along the thigh (Williams and Cohen, 2009). GTPS presents most often in middle-aged patients, with females being more commonly affected than males (4:1) (Williams and Cohen, 2009; Segal *et al*, 2007).

A systematic review on the treatments of GTPS found that traditional, non-operative therapies, such as supervised stretching and strengthening, physical therapy modalities, and corticosteroid and local anesthetic injections to the trochanteric area, have been reported to be at least transiently helpful (Williams and Cohen, 2009). Even though there are successful outcomes to the treatments, the results remain unclear. For example, symptoms will often reoccur in the long term symptoms and incomplete relief has been commonly observed when using corticosteroid injections. Non-invasive treatments were favorable for the short term, but poor available data extracted from small studies do not allow definite conclusions to be drawn regarding the best long-term treatment for GTPS. (Del Buono *et al*, 2011).

In cases where non-invasive solutions for GTPS are ineffective, surgical intervention may be required. There are multiple surgical procedures for GTPS (Nam *et al*, 2011; Ilizaliturri *et al*, 2006; Brignalli and Stainsby, 1991; Govaert *et al*, 2003; Voos *et al*, 2009; Baker *et al*, 2007). While these previous studies report some relief for most patients, others experienced no change in symptoms post surgery (Williams and Cohen, 2009). Del Buono and colleagues (2011) report that while bursectomy provided relief for 5 out of 12 patients, pain recurred for 5 patients within the time frame of the study.

Previous studies indicate that current treatments for GTPS do not consistently provide relief and may only be transiently helpful. We present an anatomical study of the region of the greater trochanter in order to document how much pressure is exerted on the greater trochanter by two different structures implicated in the development of GTPS.

We examined two of the types of surgical cuts that are used to relieve the pressure around the greater trochanter and treat GTPS in this experiment: Z-plasty (Z-cut) and ITT release (T-cut). The Z-plasty technique is a z-shaped incision of the ITT that relieves the tightness of the gluteus maximus (GMax) muscle. The original Z-plasty was described in 1991 and was developed to enable suturing of the transposed Z-incision (Brignalli and Stainsby, 1991). The ITT release is a cross-shaped incision that involves both a vertical and anterior release of the ITT called a T-cut. This procedure is used as an endoscopic technique for greater trochanteric bursectomy and for ITT release of external snap hip syndrome. Studies of both surgical techniques reported relief of GTPS pain (Ilizaliturri et al, 2006). Limitations to this type of study often include sample sizes; of possibly greater relevance is that exactly how much pressure on the greater trochanter is being relieved has not been previously documented. In addition, while these previous studies report some relief for most patients, others experienced no change in symptoms post-surgery (Williams and Cohen, 2009), which suggests that inquiry into the development of alternate surgical techniques based on a detailed anatomical understanding of this region may be warranted. Here, we preent a detailed anatomical study documenting pressure reduction around the greater trochanter contrasting the results of multiple methods.

The GMax is divided into a superficial and deep part. The entire muscle slopes inferiolaterally at a 45º angle (Drake *et al*, 2010), and the deep fibers form a tendinous structure that passes in close proximity to the greater trochanter. We hypothesize that in addition to the ITT, the tendon of the GMax also exerts force on the greater trochanter. To test this hypothesis, we contrast change in force exerted on the greater trochanter after three different types of incisions, two of which mimic current surgical procedures for treating GTPS (Z-cut and T-cut of the ITT). The third incision resects the tendon of the gluteus maximus (GMax cut). In a previous study, we observed fibers from the ITT comingling with fibers from the GMax to form a tendinous structure at the superior part of the gluteal tuberosity (Taylor *et al*, 2014). The GMax-cut involves cutting the superior part of the tendon where it attaches to the gluteal tuberosity, while leaving intact the more inferior (non-tedinos) muscle fibers that attach directly to the gluteal tuberosity. We hypothesize that the GMax tendon exerts significant force on the greater trochanter and may therefore contribute to GTPS. If the hypothesis is supported, future exploration of a surgical technique in which the GMax tendon is cut may be warranted, even though such a procedure would be more invasive than either ITT incision.

Methods

Unembalmed cadavers that were donated through the Willed Body Program at the University of North Texas Health Science Center were used for this force measurement study (n=6; 3 male and 3 female; age range from 43-88 years). All cadavers were at least 40 years old, had full knee extension, at least 30º hip flexion and extension, at least 15º hip adduction, and at least 15º hip abduction as measured by a goniometer. All measurements were made with the knee fully extended. Cadavers were excluded if the donor had undergone hip surgery during life or if they were overly obese. Cadavers were refrigerated at approximately 5ºC for up to one week postmortem to allow for blood testing ruling out infection with HIV or hepatitis. All experiments were conducted within one week postmortem.

Skin covering the anterolateral aspects of the proximal thigh were removed (Figure 1A). Two 15 cm long screws were placed through a modified plate to hold each hip in place (Figure 1B). The screws passed through the mid portion of the iliac fossa on each side of the pelvis and were anchored firmly into a large board held in place with a two C-clamps (Figure 1A). The secured plates helped to minimize movement of the cadaver while force measurements were taken. Next, a small incision approximately 6 cm in length was made to separate the tensor fasciae latae muscle and ITT for access to the greater trochanter and sensor placement.

To measure the force exerted on the greater trochanter by the ITT, we used a K-Scan System (Tekscan, Inc., South Boston, MA) portable tactile pressure measurement device equipped with a Model 5051 pressure sensor (Tekscan, Inc., South Boston, MA). This paper-thin sensor (pressure pad) has the ability to measure compressional force between tendons, ligaments, or articulating surfaces. The K-Scan System uses specifically designed scanning electronics called “handles and cuffs” that gather data from the pressure sensor using the i-Scan software package (Tekscan, Inc.).

Once the sensor was in placed over the greater trochanter (Figure 1C), we recorded to allow force measurements in Newtons (N) as the lower extremity was subjected to a range of motions at the hip joint. A series of flexion, extension, and adduction movements of the hip were carried out, and compression force in Newtons (N) was measured at 0, 10, and 20 degrees of flexion/extension of the hip joint. Each of these measurements were taken while maintaining a fixed angle of 0, 10, or 15 degrees of adduction of the hip joint. (Abduction of the hip relieves tension of the ITT at the greater trochanter, so measurements were not recorded for this hip action.) Particular pairs of measurements seen in Table 1 and 2 comparing ITT intact (Normal = I) with T-cut (T), Z-cut (Z) or GMax cut (G) will be referred to as "motion sets" for clarity. For example in Table 1, in the column for 10º Adduction with 10º Extension, cadaver C1 has 2 motion sets, one contrasting normal (I) with a T-cut (T), the other contrasting normal (I) with a GMax cut (G). Each motion set was tested for statistical difference. Three individual measurements were taken in triplicates for each data point.

The first measurements were taken with the ITT intact. Then, force measurements were taken on the same hip after surgically performing one of two ITT cuts; either a T-cut ($n = 3$) or a Z-cut ($n = 3$). After measurements were taken with the ITT intact on the contralateral hip, the GMax tendon was transected (GMax-cut) and measurements taken. Specific care was taken while making the GMax-cut to transect the superior tendinous part of the GMax only where it inserted at the gluteal tuberosity. The more inferior, non-tendinous muscle fibers attaching directly to the gluteal tuberosity were left intact. We present summary statistics for each hip. The T-cut and Z-cut of the ITT were used as a comparison to the GMax-cut to determine which procedure resulted in the greatest decrease in force on the greater trochanter. A two-way analysis of variance (ANOVA) was used to determine if there was a significant decrease in mean force between the intact ITT and the cuts performed on each hip (T-cut or Z-cut) versus the GMax-cut.

Results

Six unembalmed cadavers (3 females and 3 males; 12 hips total) were measured. On each body, a normal force measurement (ITT intact) was taken on each hip prior to making an incision in the ITT (Z-cut or T-cut) or transecting the GMax tendon. This normal force measurement with the ITT intact will be referred to as control. The summary of these experiments can be seen in Tables 1 and 2 where the mean force is reported. As indicated in Table 1, there was a significant reduction of force ($p \leq 0.05$) seen in all six cadavers (3 male; 3 female) when the force at 10º or 15º adduction of the hip was measured with either 10º or 20º extension of the hip. Table 2 offers similar results, but flexion was the primary measurement in this table. In Table 2, a reduction of force is seen in 5 out of 6 cadavers (2 females; 3 males) when the force at 10º or 15º adduction of the hip was measured with either 10º or 20º flexion of the hip. However, in some of motion sets, the force increased at the greater trochanter instead of decreasing. For example, in Table 2 for cadaver 3C at 10º adduction and 10º flexion, comparing the control (C) to the T-cut (T), force increased from 32.2 N in the control to 42.7 N in the T-cut. This variation was seen in other motion sets and was not predictable nor was it dependent on the type of incision made to the ITT or the GMax.

Only the 43-year old male cadaver C5 had no significant force reduction for any of the measured movements for flexion (Table 2). In fact, several of the motion sets for flexion in cadaver C5 show an increase in force after the ITT or Gmax cuts were made (Table 2). Overall cadaver C5 (43-year old male) had by far the least amount of force reduction comparing the normal intact ITT to either the T-cut or the GMax-cut. The only force reduction seen on C5 was when the hip was at 15º adduction and then subjected to either 10º or 20º of extension (Table 1).

The most striking result of the six cadavers was seen in an 82-year old male cadaver (C6) where 7 out of 8 motion sets contrasting the normal, intact ITT (Normal = I) to either a Z-cut (Z) or GMax-cut (G) showed a high significance of force reduction at the greater trochanter during different degrees of hip flexion (Table 2). For cadaver C6, the Z-cut reduced force in 3 of the 4 motion sets, the only exception was at 15º adduction and 10º flexion. Furthermore, all motion sets for the G-max cut showed highly significant ($p \leq 0.001$) force reduction at the greater trochanter (Table 2). Another consistent reduction of force was seen in cadaver C3, an 80-year old female. Seven of the 8 motions sets measuring force at different degrees of adduction and extension showed a significant decrease in force at the greater trochanter when the T-cut or the GMax cut was made compared to control (for 2 motions sets, $p \leq 0.05$, for 5 motion sets, $p \leq 0.001$ (Table 1).

Due to their consistent reduction in force for most motion sets, cadavers C3 and C6 were selected for more extensive data analysis. For Figures 2 and 4, the Control (blue) bar refers to the force measurement taken at the greater trochanter with the normal, ITT intact (no Z-cut or T-cut). Figure 2 represents an 80-year old female cadaver that underwent a T-cut of the ITT on the left hip and a GMax-cut on the right. In Figure 2A at 0º adduction, very little change in force was seen between the Normal and T-cut when the hip was flexed at 0º, 10º or 20º. However, at the same angle of adduction (0º), there was a dramatic increase in force once the hip was placed in either 10º or 20º of extension. This highlights some of the unexplained variation we saw in force measurements throughout this experiment. Figure 2C shows an increase in force at most degrees of flexion/extension for the T-cut compared to control; however, Figure 2E shows force reduction at all degrees of hip flexion and extension, with significant reduction at 0º flexion and 10º and 20º extension. Variability seen within the same cadaver from one position of the hip to another was not uncommon in this study. The GMax-cut was much more consistent for this cadaver (80-year old female). In Figure 2B when the GMax-cut was performed on the opposite hip, there was a significant amount of force reduction seen at 0º adduction while measuring force at 0º, 10º, and 20º flexion and 20º extension. At the 10º and 15º adduction positions on this same cadaver (Figures 2D and 2F), all motion sets data showed a significant reduction in force when the GMax-cut was performed. The execution of the GMax-cut in this cadaver provided outstanding and consistent reduction of force at the greater trochanter.

Figure 3 represent the difference between the normal ITT intact (control) and the T-cut force measurements on the left hip compared to the difference of the normal ITT (control) and the GMax-cut force measurements on the right hip seen in Figure 2. The difference in force measured from normal ITT (control) and that for the GMax-cut shows positive force reduction in Figure 3A-C. The only exception observed was an increase in force is at 10º extension in Figure 3A. Overall, the GMax-cut showed greater consistency in force reduction compared to the T-cut except for 20º extension in Figures 3B and 3C. For this graph, all pairs of data points (T-cut v. GMax cut) indicated a significant difference ($p \leq 0.001$) for every flexion/extension position.

Figure 4 represents an 82-year old male cadaver that underwent a Z-cut of the ITT on the left hip and a GMax-cut on the right. In Figures 4A and 4C, the Z-cut exhibited great relief of force at the greater trochanter at 0º and 10º adduction at all flexion points (0º, 10º and 20º). In addition, at 10º adduction both 10º and 20º extension showed a significant force decrease for the Z-cut (Figure 4C). At 15º adduction, there was no significant reduction of force at the greater trochanter using the Z-cut for flexion or extension (Figure 4E). For the GMax-cut in this cadaver, there was an overall trend in force reduction measured at the greater trochanter. At 10º adduction, there was significant reduction in force at all measured points except 20º extension

(Figure 4D). Significant force reduction was observed for all flexion data points at 15º adduction; however, there were no significant reduction in force at either degree of extension (Figure 4F).

Figures 5 represent the difference between the normal ITT intact (control) and the Z-cut force measurements on the right hip compared to the difference of the normal ITT (control) and the GMax-cut force measurements on the left hip seen in Figure 4. Overall, the GMax-cut shows reduction of force at all measured degrees of flexion and extension at 0º, 10º and 15º adduction. The only exception was at 10º extension seen in Figure 5C. For flexion, the GMax-cut only decreased force better than the Z-cut at 15º adduction where the Z-cut actually increased force during hip flexion. However, the Z-cut significantly out-performed the GMax-cut for reduction of force during flexion at both 0 and 10 degrees adduction (Figures 5A and B), as well as 10 degrees extension at 10 and 15 degrees adduction (Figures 5B and C).

Discussion

In the United States, 10%-20% of adults aged 60 years or older reported hip pain associated with greater trochanteric pain syndrome on a majority of days over a 6-week period (Strauss *et al*, 2010). Risk factors associated with greater trochanteric pain syndrome include age, female sex, ipsilateral iliotibial band pain, osteoarthritis of the knee, obesity, and lower back (lumbar, sacral region) pain (Strauss et al, 2010; Christmas, 2002; Schapira, 1986).

GTPS is caused by repetitive rubbing of the iliotibial tract (ITT) on the bursa sac associated with the greater trochanter. An anatomical observational study showed that tension around the greater trochanter was greatest between the origins of the ITT on the iliac crest to the gluteal tuberosity just inferior to the greater trochanter. An incision of the ITT was made at the iliac crest to reveal the GMax tendon inserting into the gluteal tuberosity inferior to the greater trochanter. Fibers from the ITT were often observed comingling with the GMax muscle fibers to form a substantial tendon inserting at the gluteal tuberosity. In this study, the GMax tendon was observed to pass close proximity to the greater trochanter (Taylor *et al,* submitted 2014), offering evidence to a possible link to GTPS.

In the current study, we measured how much force the ITT and the gluteus maximus (GMax) tendon exerts on the greater trochanter, and contrasted the reduction of force on the greater trochanter when cutting the GMax tendon versus the ITT (as is done in currently-accepted surgical treatment for GTPS). We hypothesize that in addition to the force exerted on the greater trochanter by the ITT, the tendon of the GMax also exerts force on the greater trochanter.

However, this study showed varied results that may be explained by our small sample size. In addition, excessive movements in the hip (>15º flexion or extension) would sometimes cause the ITT to move completely off (either anterior or posterior) of the greater trochanter, thus giving erroneous force measurements at different data points in the study. Even though both procedures showed a decrease in force at many points of measurement, significant differences between reductions of force when cutting the GMax tendon versus the ITT were not always detected. In some cases, cutting the structures resulted in increased force on the greater trochanter.

Variability among cadavers based on age and sex as well as limited sample size likely account for some of these observed inconsistencies in the data set. While we do not have sufficient evidence at this point to suggest that the GMax-cut could be a possible surgical solution to GTPS, results thus far do indicate that in some cases this incision may provide a larger decrease in force on the greater trochanter than the ITT cuts. This suggests that a larger sample that controls for age and sex might provide additional evidence for whether further explorations of GMax resection might be a viable approach to GTPS treatment.

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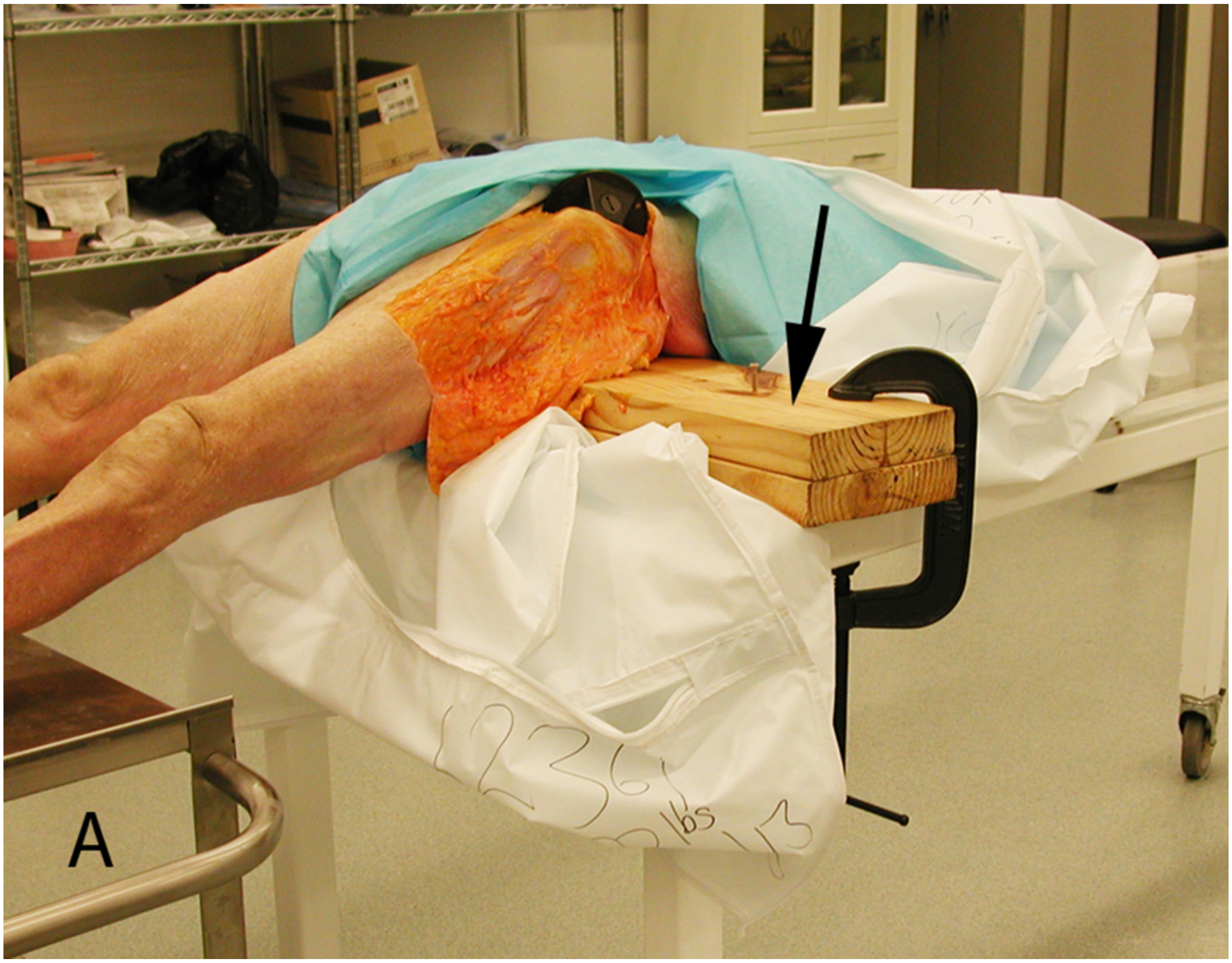


Figure 1A. Experiment preparation. Skin of the anterolateral aspect of the proximal thigh removed. The cadaver is secured with two 15 cm screws to the large board (arrow) held in place on the gurney with two C-clamps. This allowed stability of the cadaver while the hip was subjected to a range of motions.

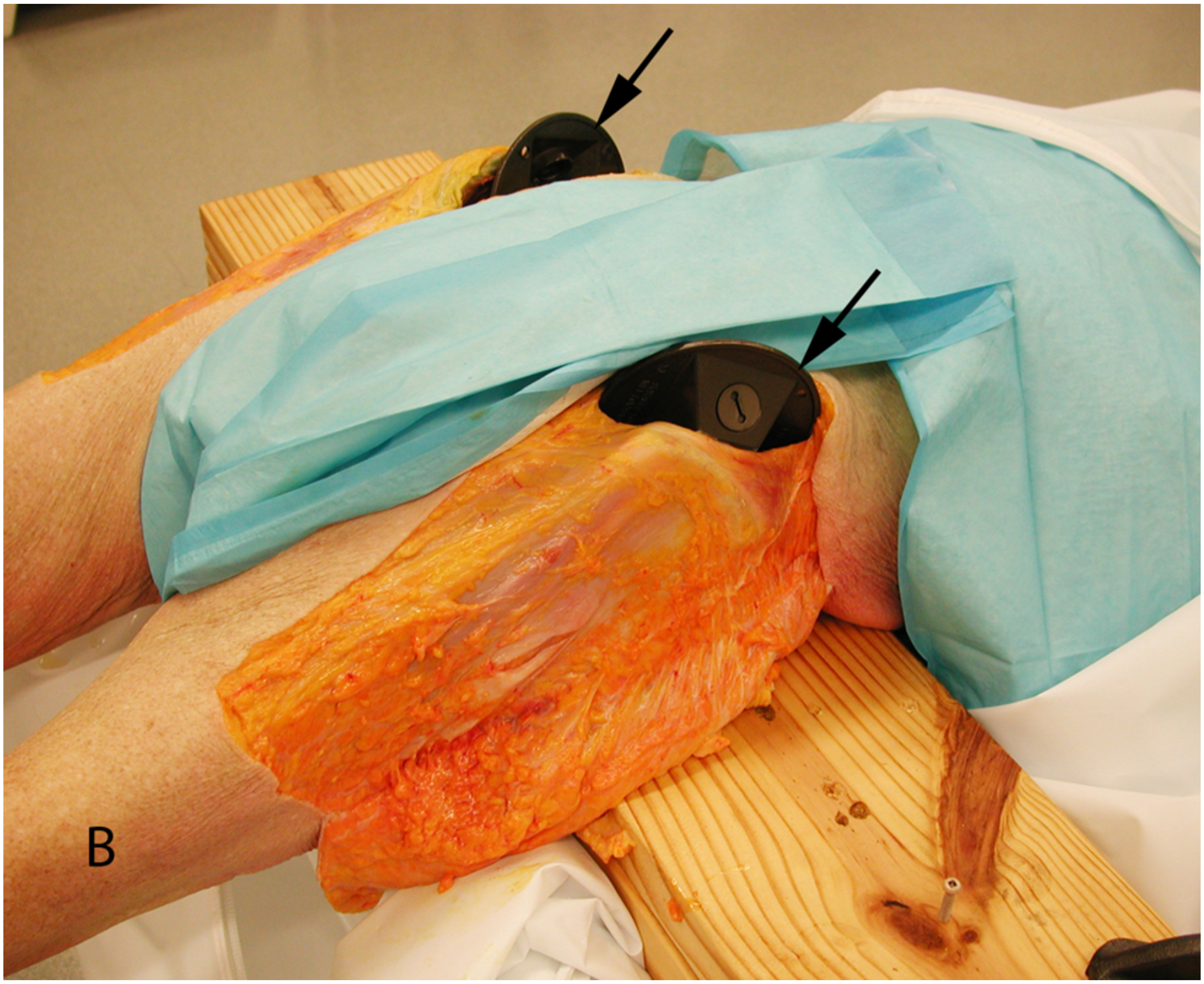


Figure 1B. Two 15 cm screws were placed through the metal plates (arrows) into the mid-point of the iliac fossa on each side of the pelvis. These were tightened securely into the board to fix the cadaver's torso while performing the range of hip movements for measurement.

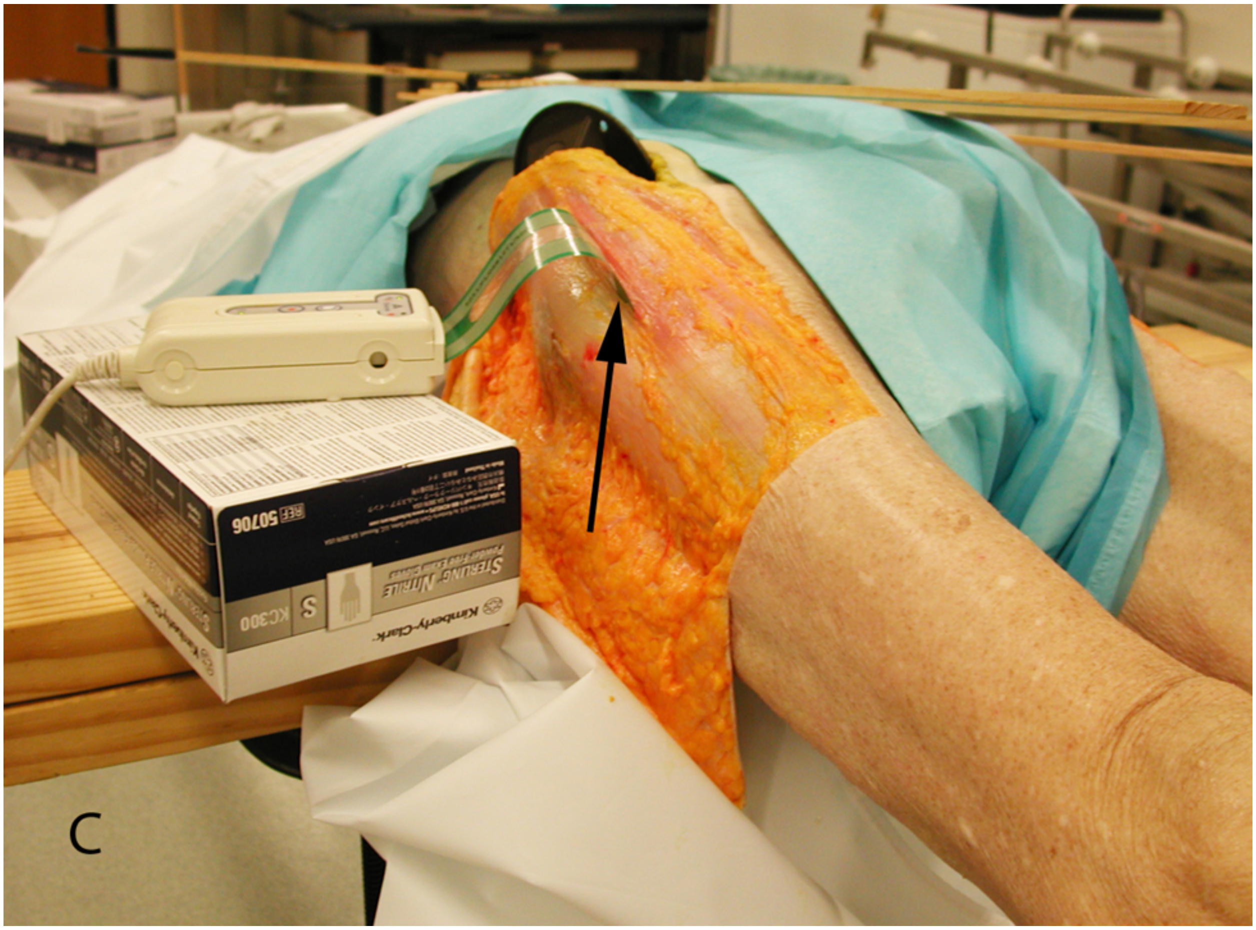
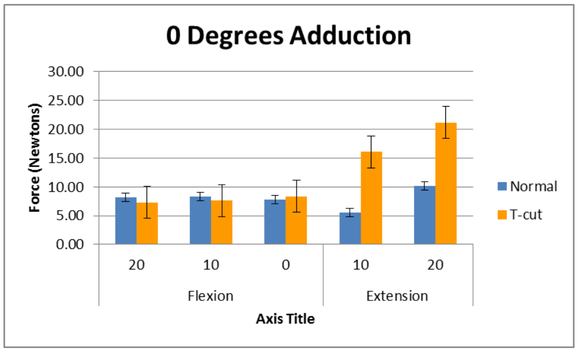


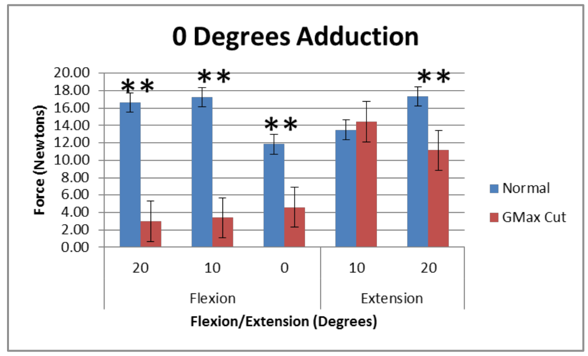
Figure 1C. The Model 5051 sensor is shown placed in the 6 cm opening between the tensor fasciae latae muscle and the ITT (arrow). Note the flexibility of the sensor pad that allows it to be placed directly over the greater trochanter superficial to the ITT. In this figure, normal ITT force (pre-cut) over the greater trochanter is being measured.

Figure 2: Contrast force exerted on the greater trochanter with intact ITT (Normal) versus force measured after incisions made on ITT or GMax in 80-year-old female cadaver.

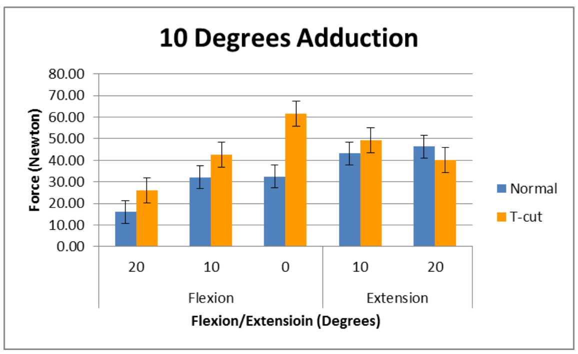
Figures 2A and B: force measurements at 0º adduction with flexion/extension for T-cut and GMax-cut. Figures 2C and D: force measurements at 10º adduction with flexion/extension for T-cut and GMax-cut. Figures 2E and F; force measurements at 15º adduction with flexion/extension for T-cut and GMax-cut. (* = $p \leq .05$; **= $p < .001$)


0 Degrees Adduction
Force (Newtons)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
20
10
0
10
20
Flexion
Extension
Axis Title
Normal
T-cut

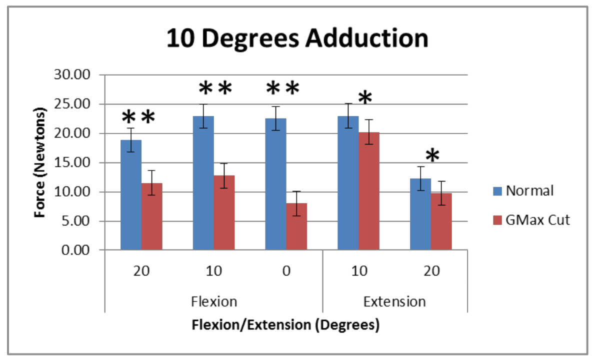
A


0 Degrees Adduction
Force (Newtons)
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
GMax Cut

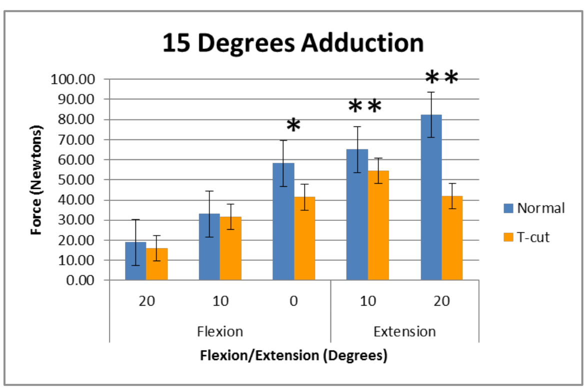
B


10 Degrees Adduction
Force (Newton)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
20
10
0
10
20
Flexion
Extension
Flexion/Extensioin (Degrees)
Normal
T-cut

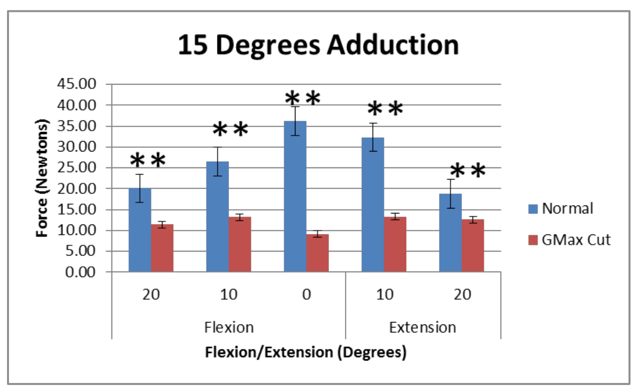
C


10 Degrees Adduction
Force (Newtons)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
GMax Cut

D

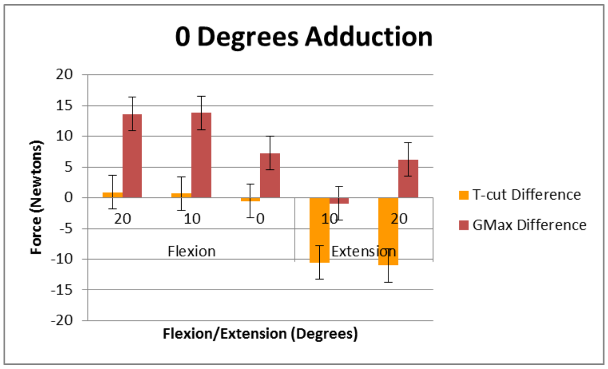

15 Degrees Adduction
Force (Newtons)
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
T-cut

E

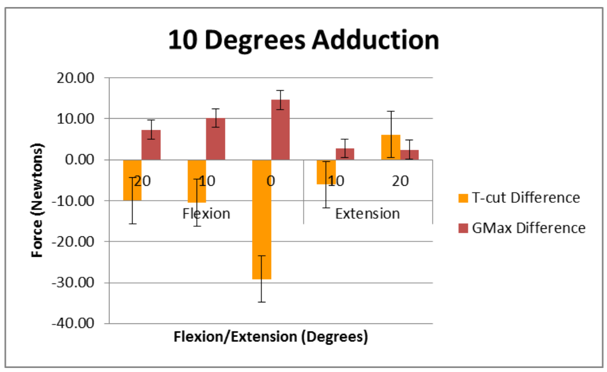

15 Degrees Adduction
Force (Newtons)
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
GMax Cut

F

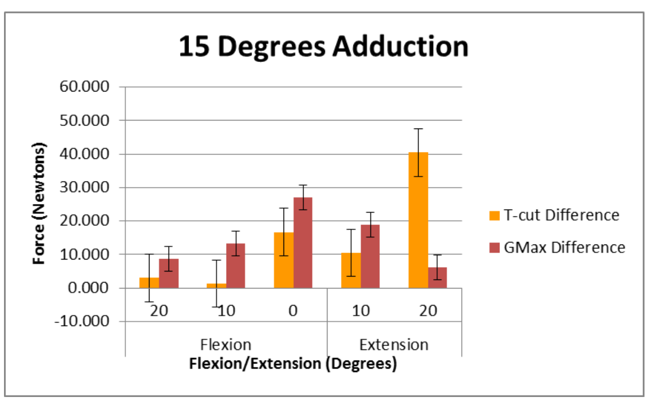
Figure 3: Contrasting the force differences seen in Figure 2 (80-year old female). Figure 3A: force differences seen at 0^o adduction with flexion/extension of the hip. Figure 3B: force differences seen at 10^o adduction with flexion/extension of the hip. Figure 3C represents force differences seen at 15^o adduction with flexion/extension of the hip. Negative values represent an increase in force. For every paired set of data points in Figure A, B, and C, all showed a p value less than 0.001.


0 Degrees Adduction
Force (Newtons)
20
15
10
5
0
-5
-10
-15
-20
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
T-cut Difference
GMax Difference

A

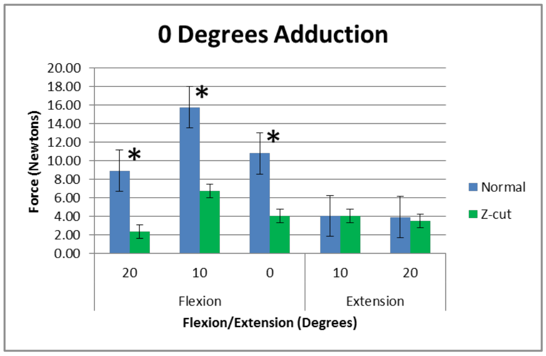

10 Degrees Adduction
Force (Newtons)
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
T-cut Difference
GMax Difference

B

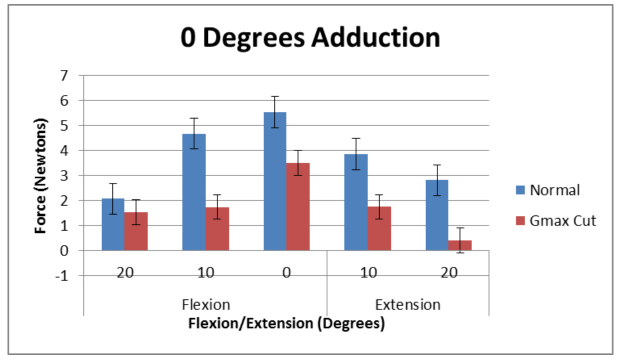

15 Degrees Adduction
Force (Newtons)
60.000
50.000
40.000
30.000
20.000
10.000
0.000
-10.000
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
T-cut Difference
GMax Difference

C

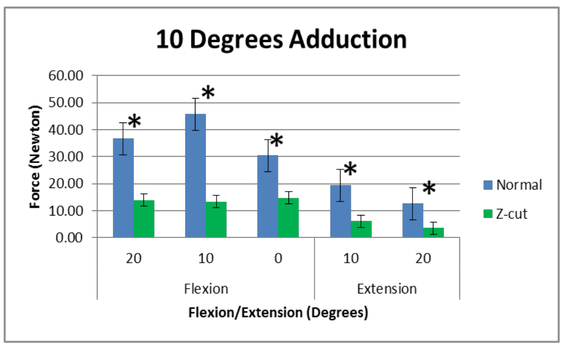
Figure 4: Contrast force exerted on the greater trochanter with intact ITT (Normal) versus force measured after incisions made on ITT or GMax in 82-year-old male cadaver. Figures 4A and B; force measurements at 0º adduction with flexion/extension for Z-cut and GMax-cut. Figures 4C and D; force measurements at 10º adduction with flexion/extension for Z-cut and GMax-cut. Figures 4E and F; force measurements at 15º adduction with flexion/extension for Z-cut and GMax-cut. (* = $p \leq .05$; **= $p < .001$)


0 Degrees Adduction
Force (Newtons)
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
Z-cut

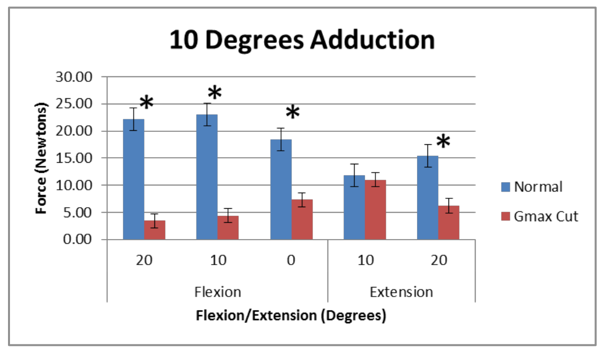
A


0 Degrees Adduction
Force (Newtons)
7
6
5
4
3
2
1
0
-1
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
Gmax Cut

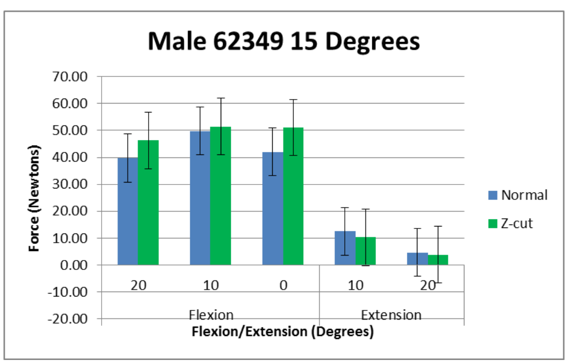
B


10 Degrees Adduction
Force (Newton)
60.00
50.00
40.00
30.00
20.00
10.00
0.00
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
Z-cut

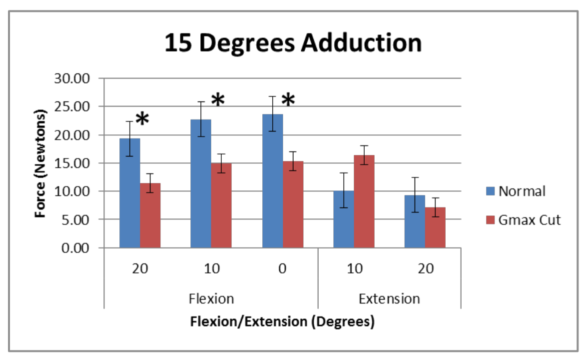
C


10 Degrees Adduction
Force (Newtons)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
Gmax Cut

D

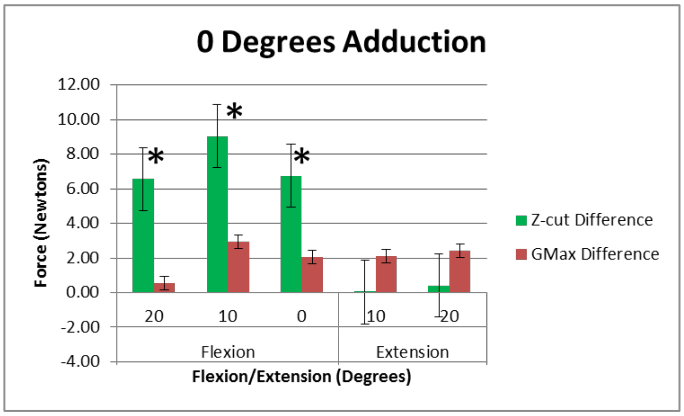

Male 62349 15 Degrees
Force (Newtons)
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
-20.00
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
Z-cut

E

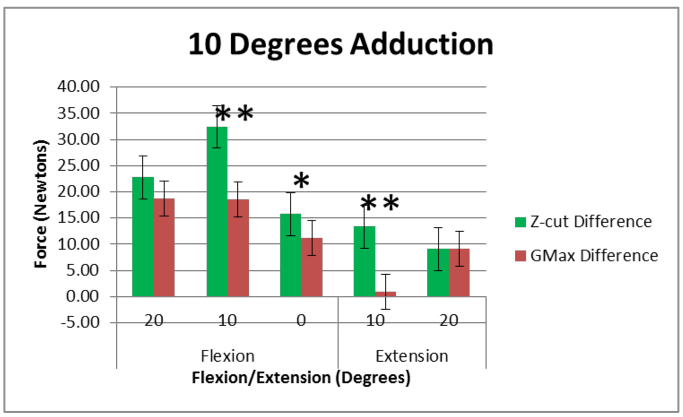

15 Degrees Adduction
Force (Newtons)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
Gmax Cut

F

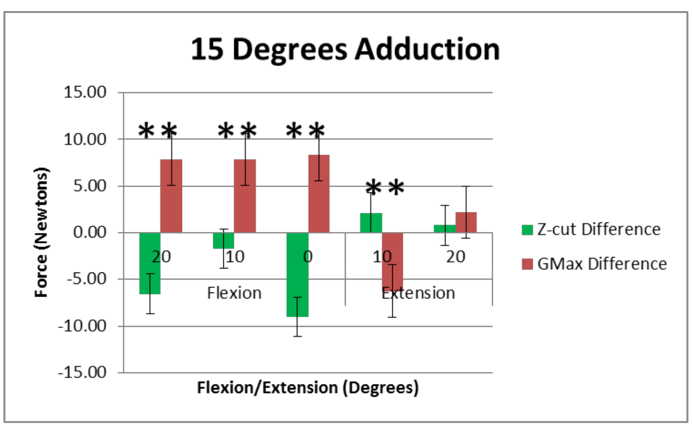
Figure 5: Contrasting the force differences seen in Figure 4 (82-year old-male). Figure 5A: force differences seen at 0^o adduction with flexion/extension of the hip. Figure 5B: force differences seen at 10^o adduction with flexion/extension of the hip. Figure 5C: force differences seen at 15^o adduction with flexion/extension of the hip. Negative values represent an increase in force. (* = $p < .05$; ** = $p < .001$).


0 Degrees Adduction
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
Force (Newtons)
*
*
*
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Z-cut Difference
GMax Difference

A


10 Degrees Adduction
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
Force (Newtons)
**
*
**
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Z-cut Difference
GMax Difference

B


15 Degrees Adduction
15.00
10.00
5.00
0.00
-5.00
-10.00
-15.00
Force (Newtons)
**
**
**
**
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Z-cut Difference
GMax Difference

C

Cad #	Sex	Age	10° Adduction 10° Extension				10° Adduction 20° Extension				15° Adduction 10° Extension				15° Adduction 20° Extension			
C1	F	65	101.9 I	12.4 Z	5.3 I	10.9 G	88.6 I	17.0 Z	2.0 I	6.0 G	16.5 I	133.6 Z	57.4 I	19.1 G	26.1 I	133.3 Z	12.9 I	12.4 G
			***				***						***					
C2	F	88	7.8 I	5.7 Z	4.2 I	5.8 G	6.7 I	4.8 Z	5.0 I	5.5 G	10.4 I	12.4 Z	10.0 I	6.3 G	5.6 I	9.2 Z	6.7 I	5.3 G
			*				*											
C3	F	80	43.2 I	49.2 T	23.0 I	20.2 G	46.3 I	40.1 T	12.3 I	9.8 G	65.0 I	54.5 T	32.3 I	13.4 G	82.4 I	41.9 T	18.8 I	12.6 G
					*		***		*		***		***		***		***	
C4	M	86	15.4 I	11.2 T	12.7 I	15.3 G	8.3 I	4.6 T	6.8 I	5.9 G	52.9 I	22.7 T	54.2 I	37.0 G	22.0 I	8.3 T	43.7 I	10.6 G
			*				*				***		***		***		***	
C5	M	43	4.7 I	9.0 T	3.1 I	1.3 G	2.5 I	4.7 T	2.3 I	1.1 G	10.5 I	15.6 T	9.4 I	4.2 G	3.9 I	9.8 T	6.6 I	2.8 G
													***				***	
C6	M	82	19.4 I	6.1 Z	11.9 I	11.0 G	12.7 I	3.6 Z	15.4 I	6.2 G	12.5 I	3.8 Z	10.1 I	16.4 G	4.6 I	3.1 Z	9.3 I	7.1 G
			***				***		***									

Table 1. Mean force measurements (represented in Newtons) at various degrees of adduction and extension. ITT intact = Intact (I); ITT incisions = T-cut (T) or Z-cut (Z); GMax tendon transection = GMax-cut (G). Statistical significance; p values are indicated by * ≤ .05, ** ≤ .01, and *** ≤ .001.

Cad#	Sex	Age	10° Adduction 10° Flexion				10° Adduction 20° Flexion				15° Adduction 10° Flexion				15° Adduction 20° Flexion			
C1	F	65	93.3 I	70.4 Z	9.5 I	5.9 G	159.3 I	92.7 Z	30.7 I	67.6 G	233.8 I	160.5 Z	55.2 I	53.1 G	229.7 I	234.4 Z	119.0 I	146.2 G
			**				***				***							
C2	F	88	14.7 I	6.7 Z	19.3 I	30.9 G	11.2 I	5.5 Z	40.1 I	46.0 G	17.7 I	11.1 Z	53.5 I	42.8 G	16.7 I	11.6 Z	78.6 I	69.8 G
			***				***				***		***		***		***	
C3	F	80	32.2 I	42.7 T	23.0 I	12.7 G	16.1 I	26.0 T	18.8 I	11.5 G	33.0 I	31.7 T	26.5 I	13.3 G	19.0 I	15.9 T	20.1 I	11.4 G
					***				***				***				***	
C4	M	86	24.7 I	25.2 T	6.4 I	14.5 G	32.4 I	32.8 T	7.2 I	11.4 G	99.1 I	70.5 T	58.6 I	40.9 G	107.2 I	99.9 T	49.4 I	24.2 G
											***		**		***		***	
C5	M	43	31.0 I	27.6 T	7.00 I	9.7 G	30.0 I	48.1 T	9.2 I	16.5 G	59.7 I	69.9 T	18.6 I	34.2 G	77.4 I	78.9 T	29.1 I	48.8 G
C6	M	82	36.7 I	13.9 Z	22.2 I	3.4 G	13.0 I	7.8 Z	15.9 I	3.6 G	39.7 I	46.3 Z	15.9 I	11.5 G	41.4 I	28.4 Z	13.3 I	5.4 G
			***		***		***		***				***		***		***	

Table 2. Mean force measurements (represented in Newtons) at various degrees of adduction and flexion. ITT intact = Intact (I); ITT incisions = T-cut (T) or Z-cut (Z); GMax tendon transection = GMax-cut (G). Statistical significance; p values are indicated by * ≤ .05, ** ≤ .01, and *** ≤ .001.

CHAPTER V

SUMMARY

A systematic review on the treatments of greater trochanteric pain syndrome (GTPS) found that traditional, non-operative therapies, such as supervised stretching and strengthening, physical therapy modalities, and corticosteroid and local anesthetic injections to the trochanteric area, have been reported to be at least transiently helpful. There have been a number of recurrences of symptoms and incomplete relief has been commonly observed when using corticosteroid injections (Del Buono, 2011). Studies say that GTPS is due to repetitive trauma by the ITT on the bursa on the greater trochanter (Strauss et al, 2010; Williams and Stevens 2009). This study clearly shows that the gluteus maximus (GMax) tendon is also contributing to the force applied on the greater trochanter. A possible reason why previous studies do not focus on the role of the gluteus maximus in GTPS is because its anatomical relationship to the ITT at the greater trochanter has not previously been examined thoroughly. In addition, the current anatomical literature does not describe the tendon complex between the GMax and the ITT where they insert into the gluteal tuberosity very well. This study was the first to show different variations of the gluteus maximus tendon (single versus multiple tendinous slips) and comingling of the fibers from both the ITT and GMax to insert into the gluteal tuberosity there has been no previous description of the ITT inserting into the gluteal tuberosity via contribution to the GMax tendon. A better understanding of the hip anatomy in the area of the greater trochanter will lead to better insight for more effective treatments for GTPS.

Iliotibial Tract and Gluteus Maximus Insertions on Gluteal Tuberosity

The ITT is a thickening of the fascia lata into a longitudinal band on the lateral thigh. It originates from the iliotuberculum of the iliac crest and inserts into Gerdy's tubercle on the superolateral tibia. Other insertions sites for the ITT include the linea aspera via lateral intramuscular septum, and lateral epicondyle (Binbam et al, 2004; Viera et al, 2007).

The gluteus maximus (GMax) is the largest muscle of the lower limb (Ward et al, 2009), as weel as the largest and most superficial muscle in the gluteal region of the human body. This muscle is organized into two layers: superficial and deep. The fibers of the superficial part of the gluteus maximus represent about 80% of the muscle's total mass and insert into the ITT (Reiman et al, 2012). The deep fibers of the inferior part of the muscle attach to the gluteal tuberosity and represent the major focus of this study. The deep fibers constitute about 20% of the mass of the GMax, and they slope inferolateraly as they insert into the femur at the gluteal tuberosity.

The deep fibers form a vertically elongated bundle of tendon and muscle fibers prior to inserting at the gluteal tuberosity. In our observations, the superior part of this bundle forms the tendinous structure we refer to as the GMax tendon, while the inferior portion is compose of muscle fibers. As these deep fibers inserts into the femur, they pass directly over the greater trochanter of the femur. Another unique observation made in the study was the comingling of fibers from the ITT and the GMax tendon. These combined structures put pressure on the greater trochanter as a person walks, which in turn, implicates this structure as a possible cause of

GTPS. However, there are a lack of studies that mention the role the GMax tendon may play in GTPS.

During the initial part of this investigation, we determined that the GMax tendon inserts into the gluteal tuberosity in multiple ways. Nearly 80 cadavers were used to study the gluteal region of the hip in this study. Nearly 40% of the tendons we observed inserted into the gluteal tuberosity as a single, large tendon. About 36% of the GMax tendons observed had two tendinous slips instead of a single tendon. The remaining had a combination of three or more tendinous slips that formed a complex at the insertion site of the deep GMax fibers. Rarely did we find four or more tendons inserting into the gluteal tuberosity. One hip had an accessory GMax muscle arising from the deep, inferior muscle fibers as part of the GMax tendinous insertion complex. However, the tendon from the accessory GMax muscle inserted on the proximal femur lateral to the intertrochanteric crest and superior to the upper boundary of the gluteal tuberosity. One additional observation made in this study, was that the number of tendons could vary from one hip to the other on the same body. For example, there could be a single tendon on the right hip, but there could be multiple tendinous slips on the opposite hip. Women are at a 4:1 risk of developing GTPS compared to men. A chi-square test was performed to see if the female cadavers in this study had more multiple insertions than the men in order to determine whether there might be a correlation between multiple tendinous and a higher risk of developing GTPS; however, there was not a significant difference in the number of tendinous slips in females versus males.

In our investigation, we report the unique observation that fibers from the GMax tendon comingle with fibers from the ITT to insert into the gluteal tuberosity. It appeared the ITT fibers inserted into the superior portion of the tendon, with fibers from the GMax contributing more to the middle and inferior portion of the tendon. If double tendinous slips were observed, fibers from the ITT could often be seen contributing to both, while fibers from the GMax contributed more to the inferior tendinous slips. However, it was not obvious whether fibers from the ITT contributed to all tendinous slips when three or four were observed. The comingling of the fibers was very obvious in our investigation, but the exact determination of fiber contribution and direction from the GMax and ITT needs further investigation.

Force Measurement on the Greater Trochanter

After a major anatomical study of site of the GMax tendon’s attachment to the gluteal tuberosity, we decided to measure the force on the greater trochanter exerted by the ITT and the GMax tendon. By simply placing a finger between the GMax tendon and the greater trochanter and manipulating the lower limb through a range of hip motions, it is possible to note substantial pressure on the fingers at certain angles of motion. After feeling this pressure, we hypothesized that in addition to the ITT, the tendon of the GMax also exerts force on the greater trochanter. Our objective was to develop a force measurement test that could measure the force exerted by the GMax tendon and ITT as they pass across the greater trochanter. The test was developed to see if cutting the GMax tendon would have a bigger decrease in force on the greater trochanter compared to cutting the ITT (a common surgical treatment for GTPS). If this study showed that cutting the GMax tendon had a greater decrease in force at the greater trochanter compared to cutting the ITT, it would suggest the GMax could be a primary cause of GTPS and not the ITT (or addition to it). Literature on GTPS focuses primarily on the ITT as it passes across the greater trochanter when a person walks. However, the GMax tendon also passes across the greater trochanter. The results from this study could lead to an alternative, and possibly more effective, treatment for GTPS.

This study allowed us to compare the T-cut or Z-cut of the ITT on one hip to the GMax-cut on the other hip. This study did not allow us to compare the T-cut to the Z-cut, because they were never performed on the same cadaver. Out of the six cadavers (3 males and 3 females) that were tested in the force study, an overall trend showed that transection (cutting) of the GMax tendon and cuts made to the ITT decreased force exerted onto the greater trochanter. However, varied results were seen from hip to hip within each cadaver, and sometimes there was not a significant decrease observed. For this study, we compared two ITT incisions, the Z-cut or the T-cut, with the GMax tendon cut (GMax-cut). In an 80- year old female cadaver, a significant amount of force was seen in the GMax cut compared to a T-cut of the ITT. The T-cut had some force reduction, but not near to the extent or as consistent as the GMax-cut. In contrast to those results, an 82-year old male cadaver had a significant amount of force reduction on both hips from a Z-cut to the ITT and the GMax-cut, with a slight edge seen for the Z-cut overall in reducing force applied to the greater trochanter. Results from these two cadavers are discussed extensively in Chapter IV. In the same study, a 65-year old female cadaver (Appendix, Figures 1 and 2) and an 86-year old male cadaver (Appendix, Figures 5 and 6) showed greater force reduction with the T-cut of the ITT compared to the GMax cut. However, neither the T-cut of the ITT or the GMax-cut had any affect on force reduction in a 43-year old male cadaver (Appendix, Figures 7 and 8). Finally, in an 88-year old female cadaver, both the T-cut and the GMax-cut had some significant reduction in force at the greater trochanter during flexion only. There was very little effect on this cadaver for either during hip extension (Appendix, Figures 3 and 4).

Preliminary Force Measurement Study

The first data collected in a pilot study of forces exerted on the greater trochanter employed a different measurement device, which proved inadequate for the study's needs. I discuss this temporary setback below.

The exclusion criteria for cadavers in this preliminary experiment were the same as reported in Chapter IV. Fresh cadavers that were donated through the Willed Body Program at the University of North Texas Health Science Center were used for this experiment. All cadavers were at least 40 years old, had full knee extension, at least 30º hip flexion and extension, at least 15º hip adduction, and at least 15º hip abduction as measured by a goniometer. All measurements were made with the knee fully extended. Cadavers were excluded if the donor had undergone hip surgery during life or if they were overly obese. Cadavers were refrigerated at approximately 5ºC for up to one week postmortem to allow for blood testing ruling out infection with HIV or hepatitis. All experiments were conducted within one week postmortem.

Skin covering the anteriolateral aspect of the proximal thigh was removed, and the cadaver was secured to the gurney as described in Chapter IV. Muscle fibers, fascia, and the ITT were moved anteriorly, but not cut, to gain access the greater trochanter. Soft tissue was cleaned off the greater trochanter, and a dime size hole was drilled to the depth of 0.5 cm on the greater trochanter for placement of the SLB-100 force transducer.

For this preliminary study, a series of flexion, extension, and adduction movements of the hip was performed to measure the force (in Newtons) at the greater trochanter. Measurements were taken at 0, 10, 20, and 30 degrees of flexion/extension and 0, 10, and 20 degrees of adduction. Adduction was fixed in each measurement at either 0, 10 or 15 degrees. Three sets of measurements were taken in triplicates. The first set of measurements were taken with the ITT intact, then a set of force measurements were taken after transecting the ITT with either a T-cut and Z-cut or the GMax-cut. A paired t-test was used to determine if the decrease in force was significant.

. After a period of about one year, we had measurements on five cadavers, with only two of the cadavers providing any form of usable data. The first two or three cadavers were used to develop a protocol for placement of the force transducer. However, The placement of the SLB-100 force transducer proved to be a more difficult and cumbersome task than predicted. Due to the small size of the SLB-100,. The transducer was about 1.5 cm in diameter, and securing it to the greater trochanter proved to be a problem that could not be resolved. Also, the surface area of the actual sensor portion of the SLB-100 force was only about 3-4mm in diameter. Compared to the Tekscan System used in our later experiments, this small surface proved insufficient to take the necessary force measurements. In addition, the ITT would pass completely off of the SLB-100 transducer during many of the hip motions in our protocol, resulting in inaccurate or no pressure measurements recorded for that particular motion.

Another major problem with this preliminary study was the small amount of force (in Newtons) registering on the SLB-100 force transducer. Rarely did we record over 5-6 N, and this made the reliability of the data questionable. At a few of the compared measurements, we could infer some trends as to possible force reduction in the GMax-cut or the T-cut; however, the overall measurements were too small and variability of the measurements too large for us to consider these data reliable. Therefore, the SLB-100 transducer was eventually abandoned to be replaced with the Tekscan system.

To highlight the inadequacy of the SLB-100 sensor for the project, I report pilot results on data from a 64-year-old female cadaver. Measurements of the force at the greater trochanter were taken on the left hip when the ITT and GMax tendon were intact (Appendix, Table 1A, control). Then, the GMax tendon was transected and force measured (Appendix, Table 1B). The greatest amount of force on the greater trochanter was observed between 10 and 15 degrees of adduction and 10 degrees of flexion. The total force measured was 6.8N (Appendix, Table 1A). When the GMax tendon was cut, there was a decrease in force to 0.7 N (Appendix, Table 1B). For the right hip, force measurements were taken first with the ITT intact (Appendix, Table 2A, Normal), and then with the ITT transected with a T-cut (Appendix, Table 2B). The force increased slightly with the T-cut compared to the GMax-cut on the left hip (Appendix, Tables 2B).

Conclusion

This study has provided valuable information regarding the tendinous insertion of the GMax into the gluteal tuberosity, and a better understanding of general hip anaotmy. Even though current anatomical literature mentions the deep fibers of the GMax muscle inserting onto the gluteal tuberosity, they rarely mention a tendon and usually show in illustrations only muscle fibers attaching to the femur. In addition, we have observed fibers from the ITT comingling with the GMax tendon as they insert into the gluteal tuberosity. This tendinous structure crosses the greater trochanter, applying pressure to the bony structure. GTPS is caused by repetitive trauma to the bursa on the greater trochanter by the ITT, there is, however, very little published data that suggests the GMax has a role. In addition, this study has shown multiple tendons can insert into the gluteal tuberosity. Future work could investigate whether multiple tendinous slips cause an increase in the force applied on the greater trochanter compared to a single tendon.

Surgical procedures to relieve pain associated with GTPS currently use incisions in the ITT to decrease pressure at the greater trochanter. This study revealed that the ITT alone may not be the only or even primary exerter of force on the greater trochanter. It was hypothesized that the GMax tendon also contributes. Results from this study, however, are still ambiguous with regard to the primary structure(s) exerting force on the greater trochanter. did not show it to be the only or primary cause either. Both the ITT and the GMax tendon exert force on the greater trochanter, and they probably play an equal role in GTPS. Future work should also address which other structures surrounding the greater trochanter might also be implicated in GTPS. In prospective studies, most- but not all- patients were satisfied with the pressure relief they experienced after surgical cuts were applied to the ITT. This study showed that not all hips had a significant reduction in force after either the Z-cut or T-cut of the ITT was made. This correlates with the prospective studies wherein not all patients experience significant change in pressure on the greater trochanter after surgery, but it may be substantial enough for the results to be positive.

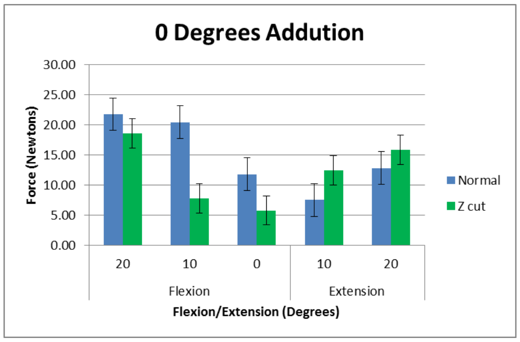
This study suggests the GMax-cut could be a potential surgical approach to treat GTPS; however, the ITT cuts might prove to be more practical because of their less invasive nature. Both the Z-cut and the T-cut are surgically very accessible and non-invasive compared to a surgical approach that involves transection of a much deeper and more substantial structure like the GMax tendon. Both the Z-cut and T-cut are very superficial surgical procedures in comparison. Even though a desired force reduction shown with transection of the GMax tendon makes this procedure a new and potential treatment for GTPS, the depth of the structure in the gluteal region might prove to be an insurmountable obstacle as a practical surgical approach.

Most likely, if non-surgical procedures are not sufficiently reducing pain in patients with GTPS, the ITT cuts will continue to be used for treatment until further studies can demonstrate superiority of an alternative surgical procedure.

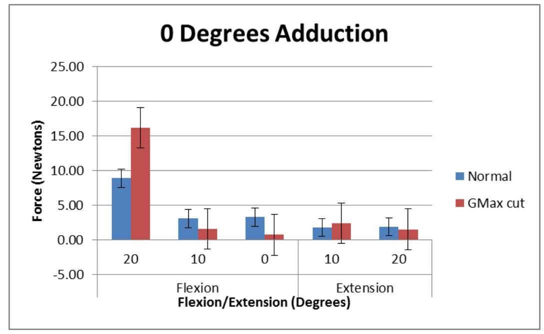
There are numerous questions that need to be resolved to have a better understanding of GTPS. In an epidemiology study, it was shown that sex, knee osteoarthritis, low back pain, and obesity can increase the risk of GTPS. However, there is no study to date that shows why these conditions increase the risk. A biomechanical study could help answer these questions. Women could be at greater risk of getting GTPS because of the width of the hips, the way they position their feet when they walk, and even the shoes they wear. We noticed in one of our force measurement experiments on a female cadaver, that just a slight lateral rotation of the leg and foot caused a dramatic increase in force at the greater trochanter. In addition, when people have low back pain and knee osteoarthritis, they will often change the way they walk in order to relieve pain. When this occurs, the gait of the hip changes. Biomechanical studies on the way people walk, with regards to foot position, and/or compensation for back/knee pain, could potentially help researchers understand the effects of other factors that contribute to GTPS.

APPENDIX

Figure 1: Contrast force exerted on the greater trochanter with intact ITT (Normal) versus force measured after incisions made on ITT or GMax in 65-year-old female cadaver. Figures 1A and B: force measurements at 0º adduction with flexion/extension for Z-cut and GMax-cut. Figures 1C and D: force measurements at 10º adduction with flexion/extension for Z-cut and GMax-cut. Figures 1E and F: force measurements at 15º adduction with flexion/extension for Z-cut and GMax-cut. (*= $p \leq .05$; **= $p \leq .01$; ***= $p \leq .001$)


0 Degrees Addution
Force (Newtons)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
Z cut

A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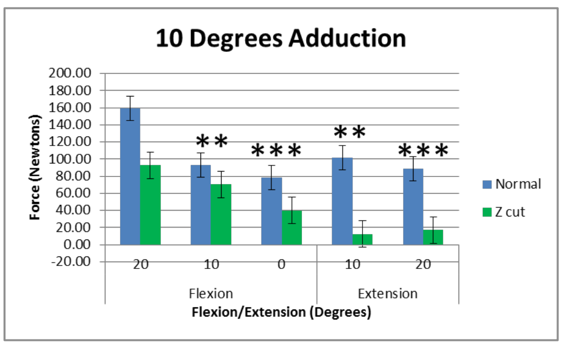
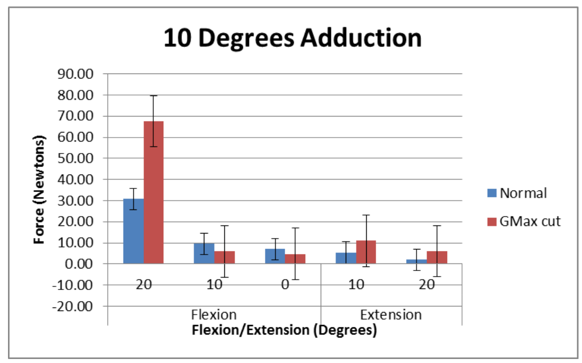
Force (Newtons)
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
GMax cut

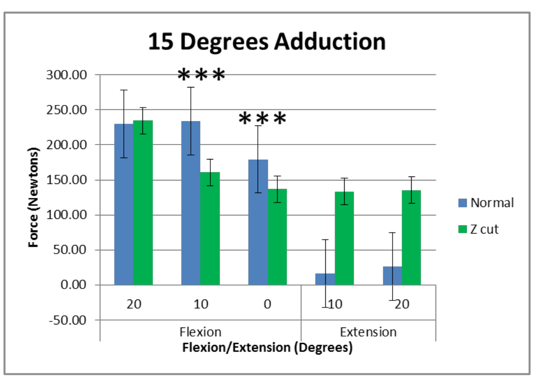
B


10 Degrees Adduction
Force (Newtons)
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
-20.00
**
***
**
***
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
Z cut

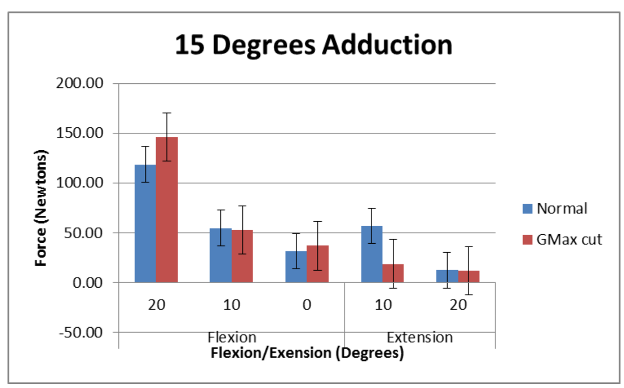
C


10 Degrees Adduction
Force (Newtons)
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
-20.00
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
GMax cut

D

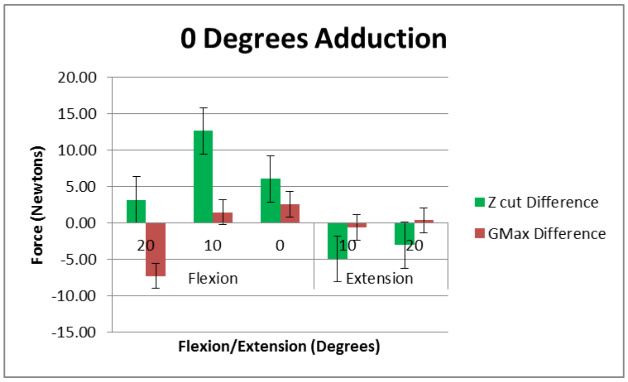

15 Degrees Adduction
Force (Newtons)
300.00
250.00
200.00
150.00
100.00
50.00
0.00
-50.00
***
***
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
Z cut

E


15 Degrees Adduction
Force (Newtons)
200.00
150.00
100.00
50.00
0.00
-50.00
20
10
0
10
20
Flexion
Extension
Flexion/Exension (Degrees)
Normal
GMax cut

F

Figure 2: Contrasting th force differences seen in Figure 1 in a 65-year old female between. Figure 1A: force differences seen at 0^o adduction with flexion/extension of the hip. Figure 1B: force differences seen at 10^o adduction with flexion/extension of the hip. Figure 1C: force differences seen at 15^o adduction with flexion/extension of the hip. Negative values represent an increase in force. (*= $p \leq .05$; **= $p \leq .01$; ***= $p \leq .001$)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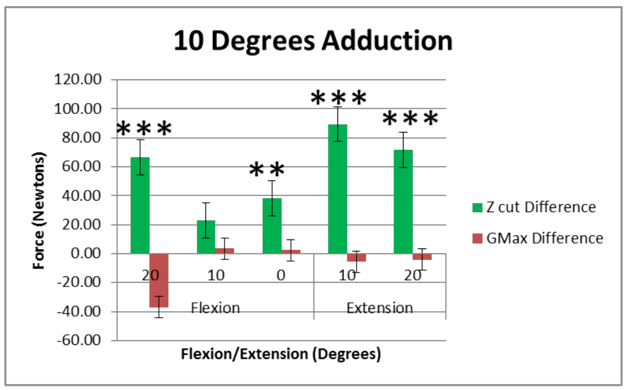
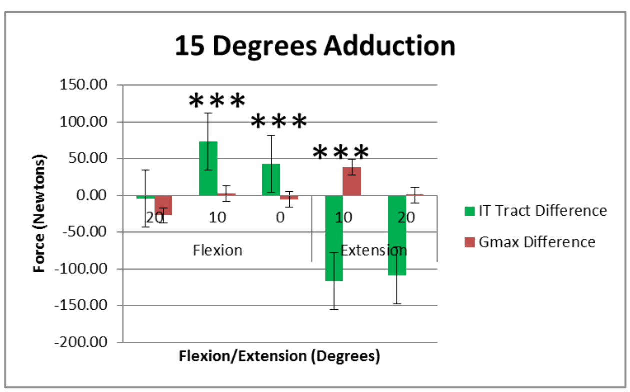
Force (Newtons)
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
-15.00
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Z cut Difference
GMax Difference

A

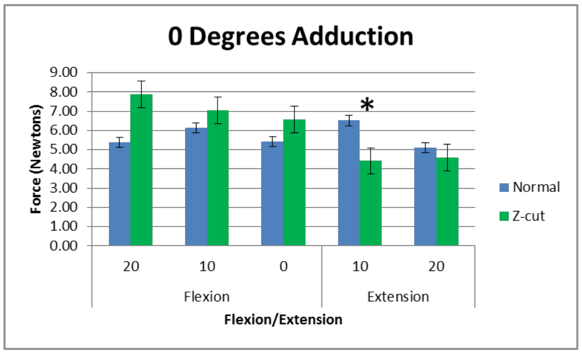

10 Degrees Adduction
Force (Newtons)
120.00
100.00
80.00
60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
***
**
***
***
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Z cut Difference
GMax Difference

B

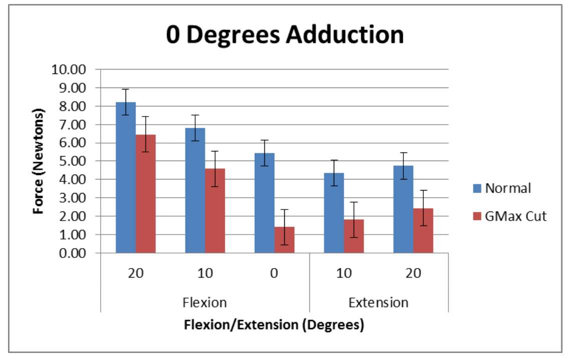

15 Degrees Adduction
Force (Newtons)
150.00
100.00
50.00
0.00
-50.00
-100.00
-150.00
-200.00
***
***
***
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
IT Tract Difference
Gmax Difference

C

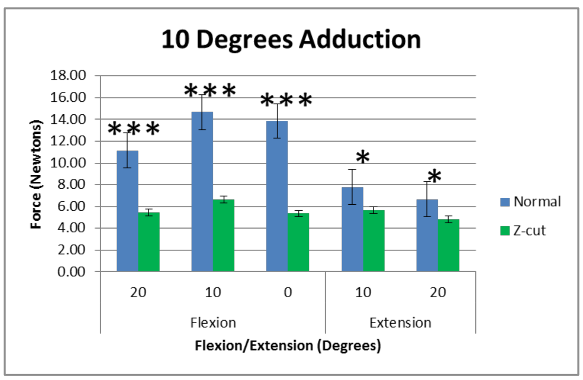
Figure 3: Contrast force exerted on the greater trochanter with intact ITT (Normal) versus force measured after incisions made on ITT or GMax in 88-year-old female cadaver. Figures 3A and B: force measurements at 0º adduction with flexion/extension for Z-cut and GMax-cut. Figures 3C and D: force measurements at 10º adduction with flexion/extension for Z-cut and GMax-cut. Figures 3E and F: force measurements at 15º adduction with flexion/extension for Z-cut and GMax-cut. (*= $p \leq .05$; **= $p \leq .01$; ***= $p \leq .001$)


0 Degrees Adduction
Force (Newtons)
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
*
20
10
0
10
20
Flexion
Extension
Flexion/Extension
Normal
Z-cut

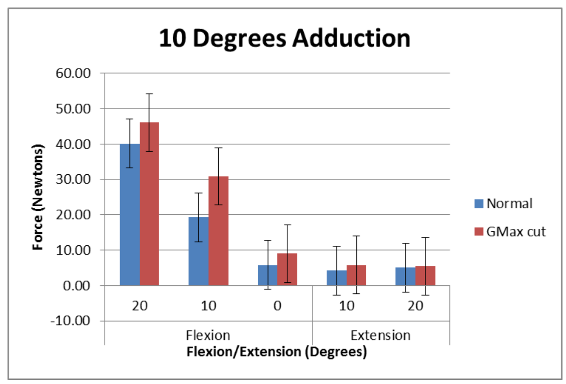
A


0 Degrees Adduction
Force (Newtons)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
GMax Cut

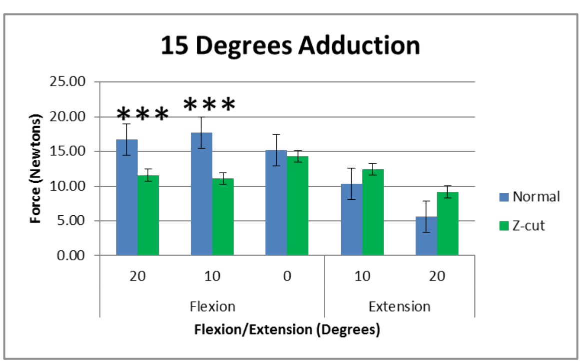
B


10 Degrees Adduction
Force (Newtons)
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
***
***
***
*
*
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
Z-cut

C


10 Degrees Adduction
Force (Newtons)
60.00
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
GMax cut

D


15 Degrees Adduction
Force (Newtons)
25.00
20.00
15.00
10.00
5.00
0.00
***
***
20
10
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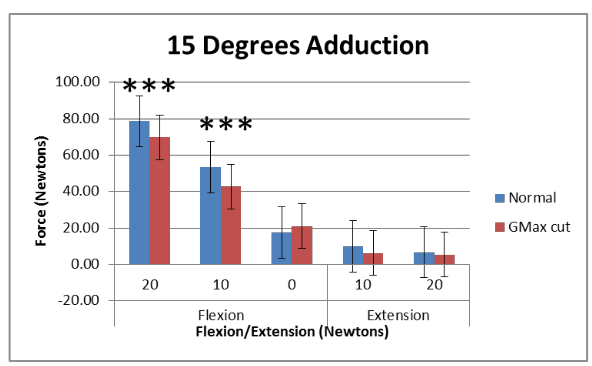
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
Z-cut

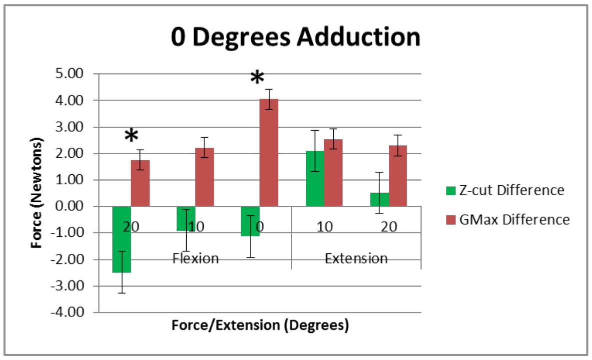
E


15 Degrees Adduction
Force (Newtons)
100.00
80.00
60.00
40.00
20.00
0.00
-20.00
***
***
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Newtons)
Normal
GMax cut

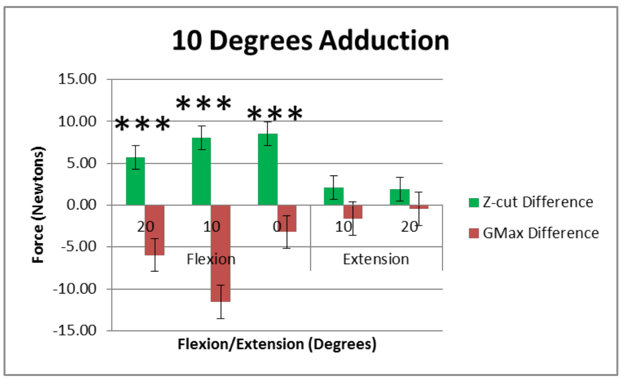
F

Figure 4: Contrasting the force differences seen in Figure 3 in an 88-year-old female.

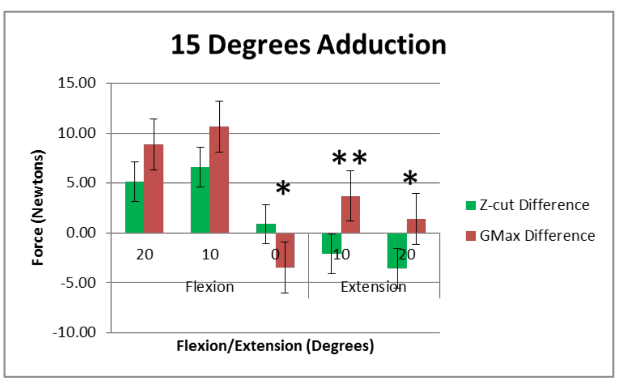
Figure 3A: force differences seen at 0^o adduction with flexion/extension of the hip. Figure 3B: force differences seen at 10^o adduction with flexion/extension of the hip. Figure 3C: force differences seen at 15^o adduction with flexion/extension of the hip. Negative values represent an increase in force. (*= $p \leq .05$; **= $p \leq .01$; ***= $p \leq .001$)


0 Degrees Adduction
Force (Newtons)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
*
*
20
10
0
10
20
Flexion
Extension
Force/Extension (Degrees)
Z-cut Difference
GMax Difference

A

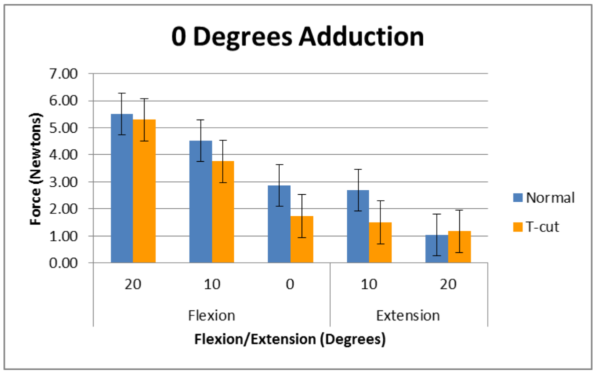

10 Degrees Adduction
Force (Newtons)
15.00
10.00
5.00
0.00
-5.00
-10.00
-15.00
***
***
***
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Z-cut Difference
GMax Difference

B

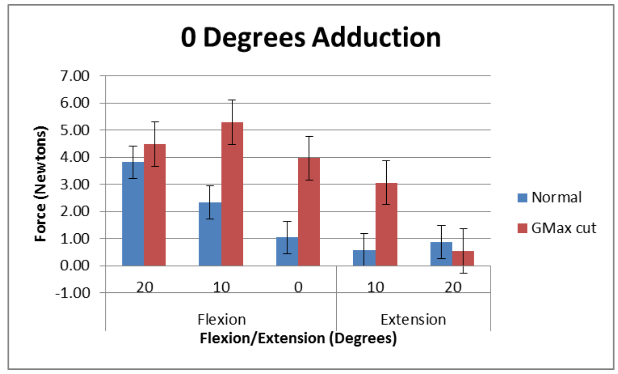

15 Degrees Adduction
Force (Newtons)
15.00
10.00
5.00
0.00
-5.00
-10.00
*
**
*
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Z-cut Difference
GMax Difference

C

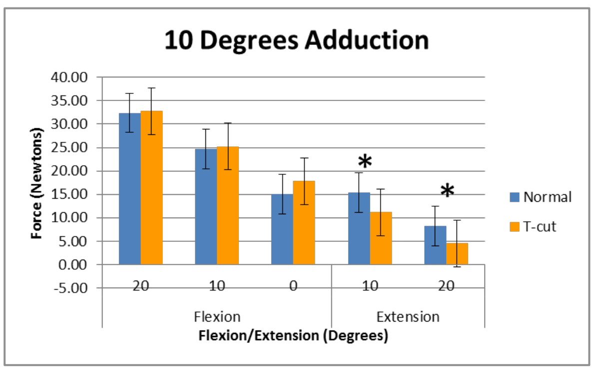
Figure 5: Contrast force exerted on the greater trochanter with intact ITT (Normal) versus force measured after incisions made on ITT or GMax in 86-year-old male cadaver. Figures 5A and B: force measurements at 0º adduction with flexion/extension for T-cut and GMax-cut. Figures 5C and D: force measurements at 10º adduction with flexion/extension for T-cut and GMax-cut. Figures 5E and F: force measurements at 15º adduction with flexion/extension for T-cut and GMax-cut. (*= $p \leq .05$; **= $p \leq .01$; ***= $p \leq .001$)


0 Degrees Adduction
Force (Newtons)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
T-cut

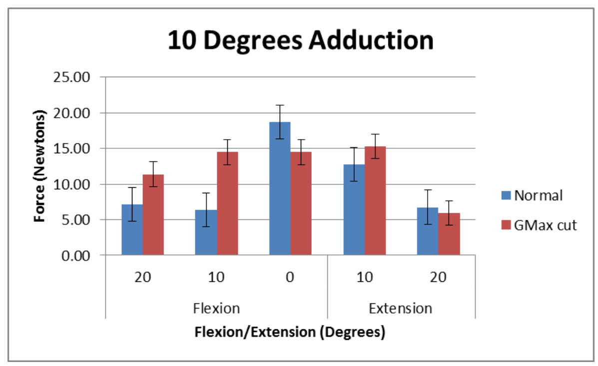
A


0 Degrees Adduction
Force (Newtons)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
GMax cut

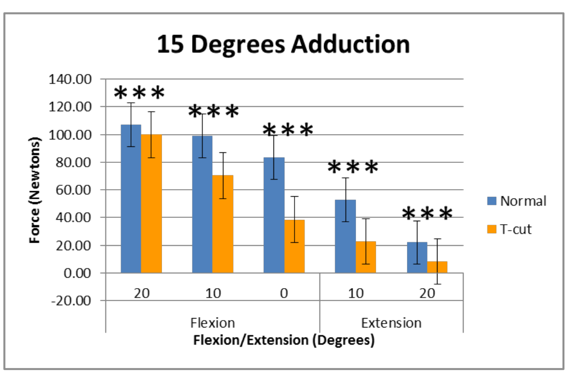
B


10 Degrees Adduction
Force (Newtons)
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
*
*
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
T-cut

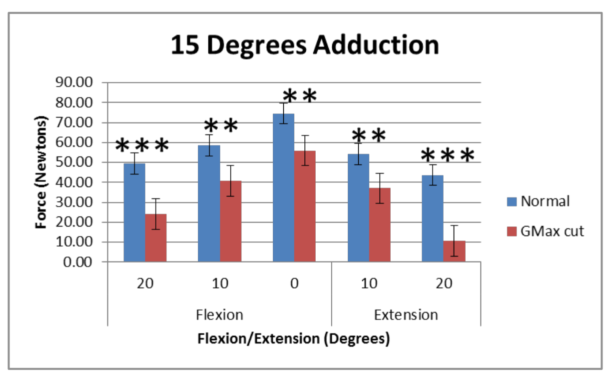
C


10 Degrees Adduction
Force (Newtons)
25.00
20.00
15.00
10.00
5.00
0.00
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
GMax cut

D

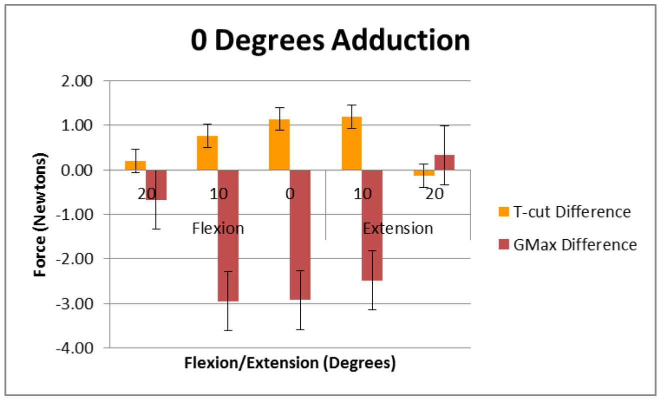

15 Degrees Adduction
Force (Newtons)
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
-20.00
***
***
***
***
***
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
T-cut

E

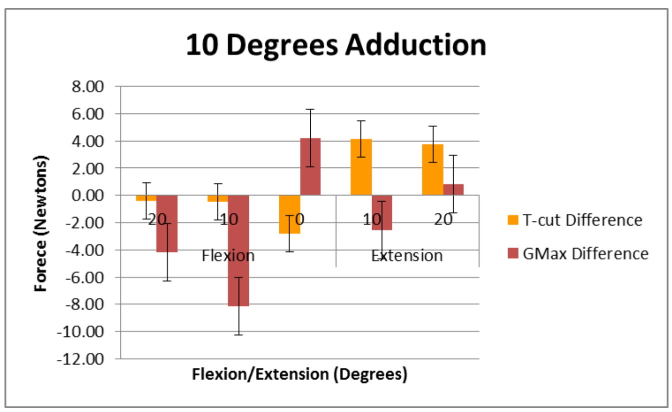

15 Degrees Adduction
Force (Newtons)
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
***
**
**
**
***
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
GMax cut

F

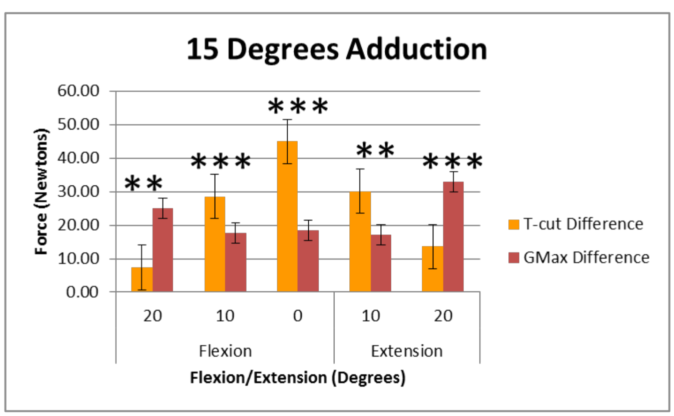
Figure 6: Contrasting the force differences seen in Figure 5 in an 86-year-old male. Figure 5A: force differences seen at 0^o adduction with flexion/extension of the hip. Figure 5B: force differences seen at 10^o adduction with flexion/extension of the hip. Figure 5C: force differences seen at 15^o adduction with flexion/extension of the hip. Negative values represent an increase in force. (*= $p \leq .05$; **= $p \leq .01$; ***= $p \leq .001$)


0 Degrees Adduction
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
Force (Newtons)
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
T-cut Difference
GMax Difference

A

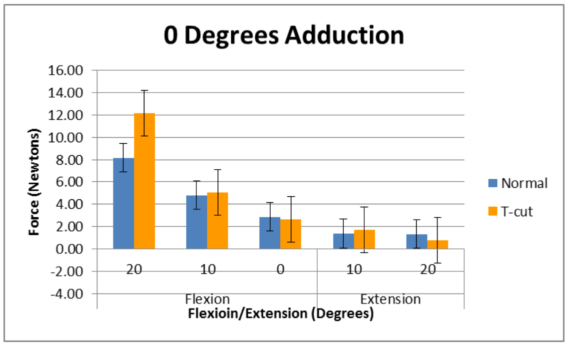

10 Degrees Adduction
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
Forece (Newtons)
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
T-cut Difference
GMax Difference

B

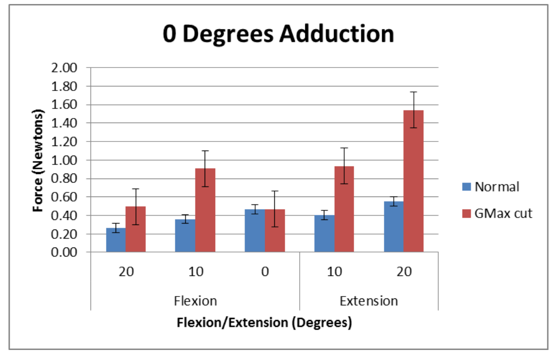

15 Degrees Adduction
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Force (Newtons)
**
***
***
**
***
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
T-cut Difference
GMax Difference

C

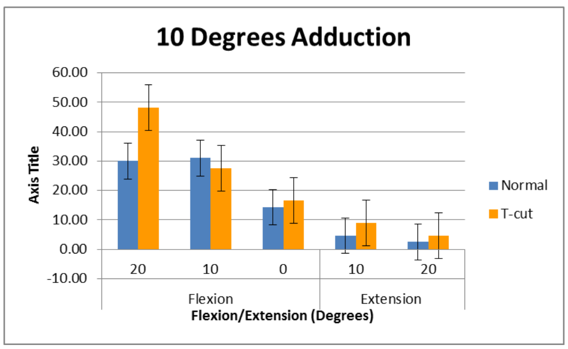
Figure 7: Contrast force exerted on the greater trochanter with intact ITT (Normal) versus force measured after incisions made on ITT or GMax in 43-year-old male cadaver. Figures 7A and B: force measurements at 0º adduction with flexion/extension for T-cut and GMax-cut. Figures 7C and D: force measurements at 10º adduction with flexion/extension for T-cut and GMax-cut. Figures 7E and F: force measurements at 15º adduction with flexion/extension for T-cut and GMax-cut. (*= $p \leq .05$; **= $p \leq .01$; ***= $p \leq .001$)


0 Degrees Adduction
Force (Newtons)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
20
10
0
10
20
Flexion
Extension
Flexioin/Extension (Degrees)
Normal
T-cut

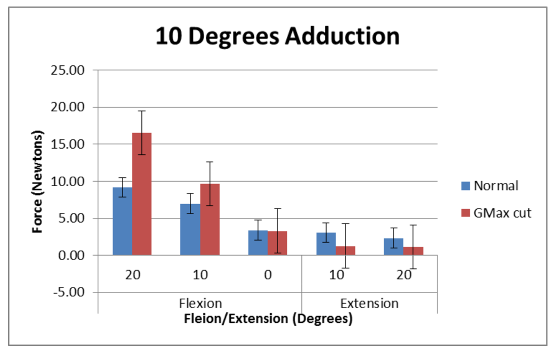
A


0 Degrees Adduction
Force (Newtons)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
GMax cut

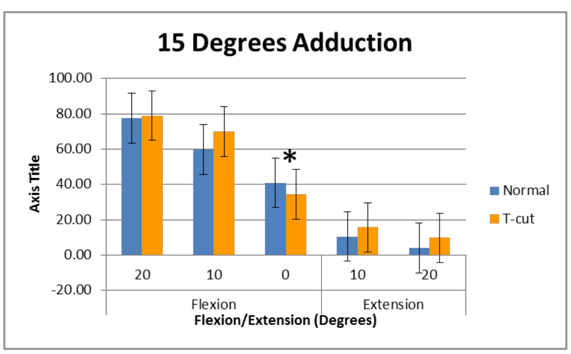
B


10 Degrees Adduction
Axis Title
60.00
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
T-cut

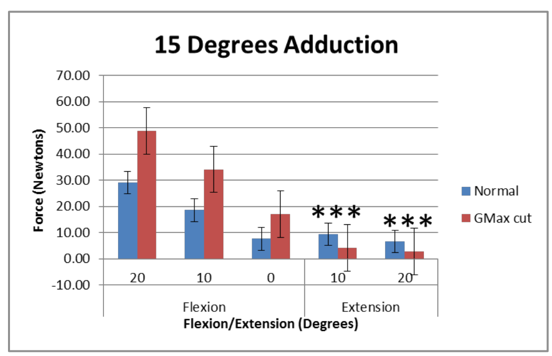
C


10 Degrees Adduction
Force (Newtons)
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
20
10
0
10
20
Flexion
Extension
Fleion/Extension (Degrees)
Normal
GMax cut

D

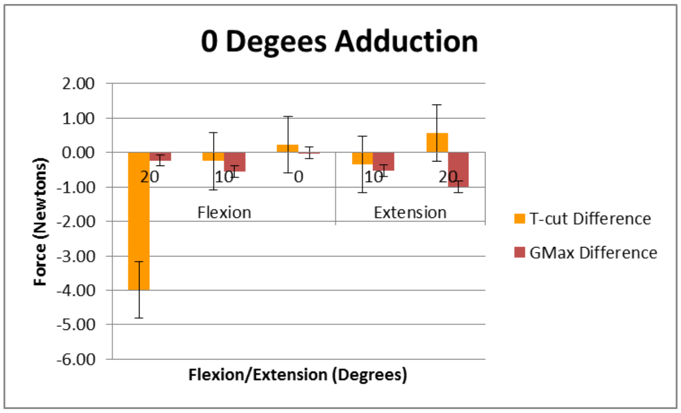

15 Degrees Adduction
Axis Title
100.00
80.00
60.00
40.00
20.00
0.00
-20.00
*
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
T-cut

E

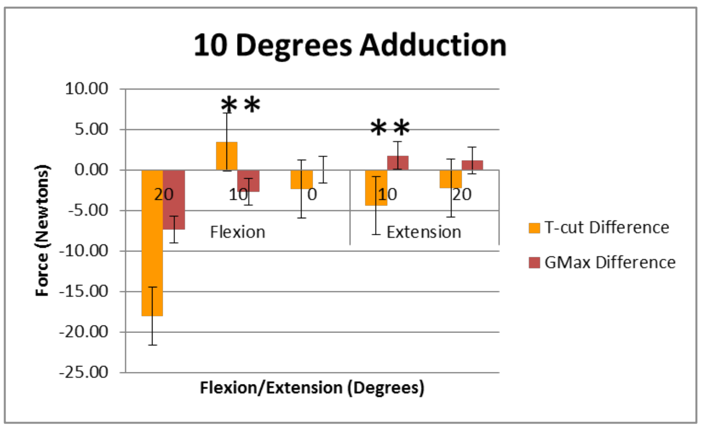

15 Degrees Adduction
Force (Newtons)
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
***
***
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
Normal
GMax cut

F

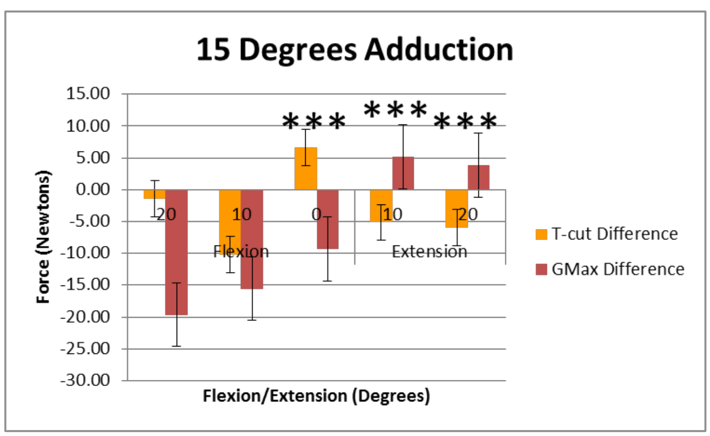
Figure 8: Contrasting the force differences seen in Figure 7 in an 43-year-old male. Figure 7A: force differences seen at 0^o adduction with flexion/extension of the hip. Figure 7B: force differences seen at 10^o adduction with flexion/extension of the hip. Figure 7C: force differences seen at 15^o adduction with flexion/extension of the hip. Negative values represent an increase in force. (*= $p \leq .05$; **= $p \leq .01$; ***= $p \leq .001$)


0 Degees Adduction
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
Force (Newtons)
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
T-cut Difference
GMax Difference

A


10 Degrees Adduction
10.00
5.00
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
Force (Newtons)
**
**
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
T-cut Difference
GMax Difference

B


15 Degrees Adduction
15.00
10.00
5.00
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
Force (Newtons)
***
***
***
20
10
0
10
20
Flexion
Extension
Flexion/Extension (Degrees)
T-cut Difference
GMax Difference

C

Table 1		A. Normal					B. Gluteus Maximus Cut		
		Adduction					Adduction		
		0^o	10^o	15^o			0^o	10^o	15^o
Flexion	30^o	0.9	1.3	2.4	Flexion	30^o	0.9	0.9	0.6
	20^o	1.0	4.1	2.1		20^o	1.2	1.0	0.4
	10^o	1.0	6.8	2.5		10^o	0.9	0.7	0.7
	0^o	0.3	4.9	6.7		0^o	0.6	0.4	0.7
Extension	10^o	0.4	0.4	0.3	Extension	10^o	0.3	0.0	0.0
	20^o	0.4	1.0	3.0		20^o	0.3	0.4	0.1
	30^o	0.6	1.5	4.1		30^o	0.4	0.1	0.0

Table 1. Force measurements over the greater trochanter at various degrees of flexion, extension, adduction, and abduction using the SLB-100 force transducer. Table 1A is the force measured at normal conditions with both the gluteus maximus tendon and the ITT intact; Table 1B is the force measured with the gluteus maximus cut. Units are in Newtons.

Table 2		A. Normal					B. ITT Cut		
		Adduction					Adduction		
		0^o	10^o	15^o			0^o	10^o	15^o
Flexion	30^o	-0.5	8.1	14.7	Flexion	30^o	0.3	12.3	35.7
	20^o	-0.6	3.9	7.8		20^o	0.0	17.5	39.1
	10^o	-0.7	0.2	2.4		10^o	0.0	7.5	3.6
	0^o	-0.7	-0.3	-0.3		0^o	-0.3	1.9	5.1
Extension	10^o	-1.5	-0.9	1.5	Extension	10^o	0.0	-0.1	-0.6
	20^o	-1.3	-0.3	0.3		20^o	-0.3	-0.3	-1.5
	30^o	-1.0	-0.3	-0.3		30^o	-0.3	-0.4	-1.6

Table 2. Force measurements over the greater trochanter at various degrees of flexion, extension, adduction, and abduction using the SLB-100 force transducer. Table 2A is the force measured at normal conditions with both the gluteus maximus tendon and the ITT intact; Table 2B is the force measured with ITT cut. Units are in Newtons.

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