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**The comparative anatomy of the minimally invasive total
hip arthroplasty one incision method using the anterior
and anterolateral approach**

By

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Declaration:

I declare that this thesis is my own, unaided work, and is being submitted in fulfilment of the requirements for the degree of Master in Science (Anatomy) to the University of Pretoria. It has not been submitted for any other degree or examination at any other University.

Signed

30th October 2015

*Dedicated to my husband and daughter,
Without whose support and patience none of this would have been possible*

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SUMMARY

The transformation in hip arthroplasty over the centuries is an evidence of the ingenuity in medicine. The evolution of hip arthroplasty is not only witnessed in the adaptation of the implantation devices, but is seen in the move from the large surgical incisions to the minimally invasive approach. This research investigated the anatomy underlying minimally invasive total hip arthroplasty when the anterior or the anterolateral approach were used. The anterior approach focused on the relation of the lateral circumflex femoral artery (LCFA) and the lateral femoral cutaneous nerve (LFCN) to various anatomical landmarks. The objective was to document whether any variations existed relating to the location and the branching pattern of the LCFA and the LFCN. The study assessed whether concerns relating to the LCFA and the LFCN, when the anterior approach was used had any merit. In the study, 90 hips were dissected for the anterior approach and 20 hips for the anterolateral approach. Simulations of the anterior approach surgical incisions were carried out by the orthopaedic surgeon on 21 hips. The anterolateral approach dissections focused on the relation of the superior gluteal vessels to the greater trochanter, anterior superior iliac spine (ASIS) and the incision site. The data collected was analysed using ANOVA with LSD and Bonferroni correction, in samples with three or more variables. Significant difference were detected for mean values from the pubic tubercle to the LCFA in the comparison of the samples 50 years and younger and those older than 50 years. In this group, p-value was also significant for the mean distances from the pubic tubercle to the straight head of the rectus femoris muscle. Statistical significance was found in the comparisons between male and female samples, the significant differences detected were for the comparisons per weight ranges and BMI.

Findings made in the study included the average distance of the LFCN from the ASIS, these measurements were documented as 13.6 mm on the left side and 12.6 mm on the right side. In this study variations in the branching pattern and the area of origin of the LCFA were noted. In 82.2% the origin of the LCFA was found to be the profunda femoris artery, with 17.8% branching from the femoral artery. The branches of the LCFA were variable, with 15.6% branching into 4 arteries, 11.1% into 5 branches and 3.3% into 6 branches. The absence of the transverse branch was noted in 4.4% of the sample size. The LFCN was found coursing on the ASIS in 5.6% of the study sample. These findings are comparable to findings made in the studies by Dixit *et al.*, (2001), Choi *et al.*, (2007) and Prakash *et al.*, (2010).

The findings made in the study, detected no significant differences in measurements taken in relation to various anatomical landmarks and neurovascular structures, when anterolateral approach was used. The study findings prove that the concerns relating to the course and distribution pattern of the LFCN and the LCFA when the anterior approach was used, could be overcome when the anatomy of the hip joint and the thigh was understood. However, it is important to note the possible variations that exist in the course of the LFCN and the branching pattern of the LCFA.

Key words: Lateral circumflex femoral artery (LCFA), lateral femoral cutaneous nerve (LFCN), minimally invasive total hip arthroplasty (MIS-THA), anterior approach, profunda femoris artery, femoral artery

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Chapter 1

Introduction

1.1. Background

The concept of hip arthroplasty started with the idea of removing the hip joint, to actual replacement of the joint surfaces with various artificial substances (using materials such as glass, plastic, pig's bladder, ivory, ceramic polyethylene (PE)) and to the now popular metal-on-metal hip replacement (Gomez and Morcuende, 2005; Abdulkareem, 2013). The overall goal of hip arthroplasty is to ensure that the produce results in a painless, freely mobile and stable joint and for the patient to return to function post-surgery (Keggi and Grey, 2005; Myers and Leahy, 2008; Brown *et al.*, 2008; Hozack and Klatt, 2008; Bal, 2008). In cases such as osteoarthritis this may require the replacement of both the pelvic and femoral components (Ring, 1968).

The history of hip arthroplasty dates back to the 1700's when the foundation for the methods we know today was laid by Henry Park (1744-1831) (Park, 1782). Since then, the technique has changed, new methods have been introduced and the incision length is also an area of interest for surgeons (Kennon *et al.*, 2004; Pour *et al.*, 2005; Bal, 2008; Hozack and Klatt, 2008). Total hip arthroplasty has evolved from the Hueter technique to the now popular Smith-Petersen technique. The Hueter technique entails surgery performed with the patient in a supine position, a vertical incision which extends about 15 cm down from the ASIS is made. This vertical incision passes between the sartorius and the tensor fasciae latae muscles, then lateral to the rectus femoris muscle and down to the capsule of the hip joint. The anterior capsule of the hip joint is exposed by blunt dissection (Hueter, 1883; Judet & Judet, 1950). The Smith-Petersen technique on the other hand involves using the area between the fascia of the sartorius muscle and the fascia of the tensor fascia latae muscle to access the hip joint (Smith-Petersen, 1949; Lovell, 2008) while at the same time focusing on the reduction of the incision length.

Several approaches and methods have been investigated by authors such as Keggi and Grey (2005) and Bal (2008). These different methods all have the objective of finding a technique that causes the least structural damage, but allows the greatest access to the head of the femur for the placement of the acetabula component (Bal, 2008). As part of the emphasis on reduced surgical trauma in total hip arthroplasty (THA), utilisation of the direct anterior approach through the interval between the tensor fascia latae (TFL) and rectus femoris has been promoted (Myers and Leahy, 2008). This approach is advised by surgeons, as the dissection is

entirely within intermuscular planes (Mattingly, 1995; Kennon *et al.*, 2004; Trousdale, 2004; Keggi and Grey, 2005; Keggi and Rubin, 2008).

The anterior approach was popularized by Smith-Petersen by modifying the Hueter technique (Hueter, 1883; Judet and Judet 1950) to his specifications (Smith-Petersen, 1917; Smith-Petersen, 1949). Smith-Petersen (1923) had observed a smooth membrane around a piece of glass when he was encouraged to design a glass mould that would be placed between the femoral head and the acetabulum. This device, according to Smith-Petersen's reasoning, would "guide nature's repair" of the joint. In 1932, Smith-Petersen began implanting these devices, and it is also at this time that he described the anterior surgical approach to the hip (Smith-Petersen, 1948; Gomez and Morcuende, 2005; Hernigou, 2013).

According to a study performed by Hozack and Klatt (2008), data demonstrated that the surgical time and blood loss were less when the Smith-Petersen approach was used compared with the modified Hardinge approach (Hozack and Klatt, 2008). Hardinge (1982) approached the hip anteriorly after the release of the anterior two thirds of the gluteus medius into the vastus lateralis, maintaining a continuous musculotendinous sleeve (Hardinge, 1982; Mattingly, 1995).

Another interesting but yet controversial point is the length of the incision necessary and appropriate for hip arthroplasty. The emphasis has been partly cosmetic, to decrease the size of the incision, but a more important goal is to minimize trauma to the muscles and soft tissue (Hozack and Klatt, 2008). The procedure is usually performed using incisions ranging from 5cm to 12cm in patients with a higher BMI (in the ranges of 25.1 – 30 kg/m² and higher than 30 kg/m²). Debate continues over the use of small-incision surgery. There is not yet any conclusive scientific data available that a small incision benefits the patient. A small incision does, however, give patients the hope that a positive outcome will be achieved and that the healing process might be quicker (Duwelius and Dorr, 2007; Soriali *et al.*, 2008; Mast and Laude, 2011; Werner and Brown, 2012).

1.2. Surgical approaches to the hip joint

Several surgical methods for performing THA were mentioned by Mattingly (1995) in his article on "Surgical Exposures for Primary Total Hip Arthroplasty" (Mattingly, 1995). Mattingly (1995) assessed different techniques, such as the anterior iliofemoral approach, anterolateral approach, lateral approach and the posterolateral approach. The advantages and

disadvantages of the different procedures were highlighted by Mattingly with the anterior approach showing the least dislocation rates and muscle damage (Mattingly, 1995). The anterolateral and direct lateral approach were also seen as the next best approaches as patient outcomes were positive when these approaches were used and lower incidences of dislocations noted (Carlson *et al.*, 1987; Mostardi *et al.*, 1988; Mattingly, 1995). These improvements are also supported by several authors including Sköldenberg *et al.* (2010) who noted, the reduction in dislocation rates after hip arthroplasty for femoral neck fractures, when they changed from using the posterolateral to the anterolateral approach.

Mattingly (1995) highlighted the advantages of the anterior iliofemoral approach as permitting excellent visualisation of the inner and outer iliac regions, the anterior and superior acetabulum and the anterior femoral head and neck. This approach allows the hip to be dislocated anteriorly with minimal risk of injury to the femoral head blood supply. The posterior capsular and muscular tissues are not disrupted. The disadvantages, however, include poor visualisation of the posterior and inferior acetabulum, poor femoral canal access and high incidence of heterotopic bone formation (Mattingly, 1995).

The anterolateral approach with all its advantages such as decreased incidences of postoperative dislocation does have some disadvantages. However, these disadvantages include injury to gluteus medius during femoral canal preparation for the insertion of the replacement component, poor exposure of structures posterior to the posterior acetabular rim and limited exposure of the interior femoral canal distally (Mattingly, 1995).

The lateral approach allows for preservation of femoral head blood supply, excellent exposure of the acetabulum and proximal femur, and retention of soft tissues to limit the incidence of postoperative posterior dislocation of the hip. Disadvantages of this approach include increased incidence of abductor muscle weakness, prolonged limp, and heterotopic bone where bone tissue would form outside the skeleton. The surgical procedure is also limited by the retention of the posterior fibres of gluteus medius and the greater trochanter. The posterior fibres of gluteus medius and the greater trochanter interfere with the ability to gain leg length during surgery and may limit access to the interior femoral canal distally for the femoral canal preparation, and provide poor exposure to structures posterior to the posterior acetabular rim (Mattingly, 1995).

The posterolateral approach, being the least favourable, does show decreased operative time, excellent exposure with minimal muscle damage, and fast rehabilitation. The disadvantages

show possible structural damage to the sciatic nerve and branches of the medial femoral circumflex artery. Frequent injury to the posterior retinacula blood supply to the femoral head makes the posterior approach a poor selection for surface replacement arthroplasty (Mattingly, 1995).

1.3. Minimally invasive procedure

The current definition of minimally invasive surgical (MIS) procedure THA includes any hip replacement procedure in which the wound length and surgical dissection are modified in an attempt to reduce the tissue trauma associated with hip replacement (Jando *et al.*, 2004). For a hip replacement procedure to be truly “minimally invasive”, the hip replacement procedure need not necessarily be performed via the smallest possible skin incision. It is essential though that the procedure be performed with minimal soft tissue trauma. Tissue structures that are not divided cannot cause pain, while over-stretched soft tissues can cause pain and delay healing (Nakata *et al.*, 2009; Gang *et al.*, 2010; Moskal *et al.*, 2014).

1.4. The two-incision approach versus the one-incision approach to minimally invasive total hip arthroplasty

Some authors have indicated the need for the use of a second mini incision when using MIS-THA. It has been documented that in some instances this second incision can lead to earlier discharge and return to function after surgery when compared with traditional methods of performing THA (Berger, 2003; Duwelius, 2006). The two-incision MIS approach was developed by Mears (Mears, 2003) and refined by Berger (Duwelius *et al.*, 2003; Berger 2004; Berger and Duwelius, 2004). This method entails using intermuscular and internervous planes to gain access to the hip joint while minimising the disruption of muscles and tendons (Jando *et al.*, 2004). The second incision is at times used for femoral component placement when the acetabular component is inserted using the anterior approach (Light and Keggi, 1980; Berry and Berger, 2003). The femoral component can however still be inserted along with the acetabular component through one incision, therefore creating a debate on whether the second incision is necessary. In a study performed by Brown *et al.* (Brown *et al.*, 2008), early complications of primary total hip replacement performed with a two-incision MIS technique were investigated and significant differences were detected in intraoperative blood loss for the two-incision group. Nerve complications occurred only in the two-incision group.

Bal (2008) who has experience performing both the one-incision and two-incision approach to MIS-THA, cited certain advantages of the one incision approach over the two incision method. He noted that the risk of thigh numbness, caused by injury to the lateral femoral cutaneous nerve (LFCN), is reduced when using the anterolateral Smith- Petersen (SP-THA) approach. Bal (2008) also noted that by avoiding blind instrumentation of the femur through a small buttock incision, intramuscular buttock hematoma could be prevented. Total blood loss during this procedure is less with the SP-THA method and by moving to the single anterior incision technique, the acetabulum and the femur are better exposed during the SP-THA procedure. With the femur elevated, the risk of fractures is smaller. With SP-THA the broach can be left in place after seating in the femur, and various neck/head combinations can be used to optimize the neck length and hip offset which would lead to better exposure of the femoral neck and would make reaming and insertion of the femoral component easier. When using the two-incision THA, the femoral stem is usually implanted first, and trial reductions with the broach left in place are not possible. There is improved surgical exposure and avoidance of blind femoral preparation when the SP-THA procedure is used. The one-incision approach also made surgical exposure relatively simple, and circumferential visualisation of the acetabulum possible (Bal, 2008).

The potential advantages of minimal-incision THA through all approaches proposed by its advocates, are decreased blood loss, less pain, faster rehabilitation, fewer dislocations and fewer thromboembolic events (Keggi and Grey, 2005).

Compromised surgical exposure through deliberately short incisions, has been found to reduce visualisation of the hip joint, which can lead to unexpected fractures, neurovascular injury, and component malposition (Keggi and Grey, 2005).

1.5. Problem Statement

Compelling evidence from previous studies (Trousdale, 2004; Bal, 2008) implicates injury to the lateral femoral cutaneous nerve (LFCN) and the lateral circumflex femoral artery (LCFA) as major drawback to the anterior approach in THA. Insufficient knowledge of the anatomy of the anterior thigh relating to the anterior approach to hip arthroplasty could possibly lead to intra-operative bleeding if the ascending branch of the LCFA is transected by mistake (Keggi and Grey, 2005; Yerasimides and Matta; 2005). Possible transection of the LCFA ascending branch is not the only concern. Thigh numbness, which might result due to the transection of

the LFCN and/or one of its branches has equally been reported (Bal, 2008). Therefore, a sound knowledge of the anatomy of the region is imperative as patient lives could be lost if the surgeon transects vessels which could otherwise be circumvented.

This study investigated the anatomy underlying THA anterior approach method, and focused on the anatomical structures that might possibly be damaged during this procedure.

Chapter 2

Aims and Objectives

2.1. Aims

The first aim of the study was to determine the anatomy underlying the anterior and anterolateral approach in MIS-THA using the one incision method, with special reference to the possible structural damage to the neurovasculature, specifically the lateral circumflex femoral artery (LCFA) and lateral femoral cutaneous nerve (LFCN) during the surgical procedures. In addition, variations in the branching pattern and course of the LCFA and LFCN were noted as these have direct bearing on post-surgical complications.

The study also proposed to investigate the merits associated with the anterior approach and compare that with the anterolateral approach in terms of the anatomy of these approaches. The study furthermore, intended to determine whether the high learning curve associated with the anterior approach could be overcome when the anatomy of the region is clearly understood.

2.2. Objectives

The objectives of this study were the following:

- To examine the anatomy underlying MIS-THA when the anterior one incision method is used, noting the possible anatomical structures that might be damaged during the procedure when the anterior and anterolateral approach was simulated by an orthopaedic surgeon on cadaver material.
- To study the anatomy of the structures located between the skin overlying the hip joint and the anterior capsule of the hip joint.
- To assess possible damage to the anterior cutaneous branches of the femoral nerve, as well as the branches of the genitofemoral nerve.
- To measure the distance between the anterior capsule of the hip joint and the neurovascular structures (LCFA and LFCN).
- To assess the course and possible variations of the LFCN and the specific branches that might be damaged which may cause thigh numbness to the anterior and lateral aspects of the thigh after surgery.

- To assess the course and possible variation of the LCFA by studying the branching pattern at the origin of the ascending and descending branches, noting which specific part is at risk of damage during surgery.
- To compare the current data available on the variations and branching patterns of the LCFA with data collected in this study.

Chapter 3

Literature Review

3.1. Introduction

The basis upon which hip arthroplasty is founded, were used as a way of treating those medical conditions that resulted in limited or no movement of the hip joint. Arthritis *deformans* being a part of the class of these debilitating disorders is seen as one of the common causes to hip joint related disease. The scope of hip arthroplasty now extends to a number of disorders in which the joint and/or the articulation components have become diseased (Whitman, 1924; Gomez and Morcuende, 2005).

The range of diseases that result in failure of the joint to fully perform its function include avascular necrosis of the femoral head, developmental dysplasia, Perthes' disease, malignancy, Paget's disease as well as femoral neck fractures amongst others (Abdulkareem, 2013). The scope of joint related medical conditions that result in a variety of conditions are corrected with hip arthroplasty, in such instances either the acetabulum, head of the femur or femoral neck would need replacing.

In the following sections, hip arthroplasty will be discussed in greater detail with special attention paid to the different approaches to the modern day techniques and adaptations of the different methods used in clinical settings. The discussion will also address the different replacement components used during hip arthroplasty. The chapter will attempt to map out the history along with the scholars that contributed to the arrival at MIS-THA.

3.2. The need for arthroplasty

The reconstruction operation of the hip joint was originally devised for fractures that were not united, particularly for cases where the neck of the femur had been absorbed or worn away. Function was impaired by the loss of the femoral neck which limited abduction of the leg at the hip joint (Whitman, 1924; Watson-Jones, 1936; Girdlestone, 1982). In such instances, where the fractures were not united, it was evident that limited movements could be performed through the joint with the greatest concern being the amount of pain experienced by the patient when the hip joints were not immobilised. The lack of immobilisation of the hip joint resulted in further damage to the hip joint. The difficulties experienced relating to the hip joint created the need to correct the malfunctioning of the hip joint by regaining mobility and reducing or

eliminating the amount of pain experienced. The ultimate goal was therefore to allow the hip joint to return to normal function and to eliminate the cause of the joint immobility.

3.2.1. Fractures to the neck of the femur

One of the factors that lead to the need for hip arthroplasty to be performed, was fractures of the neck of the femur. In the attempt to find a solution to the decrease in functionality due to the injury to the neck of the femur, it was important to understand the cause of the fractures. Fractures to the neck of the femur may be due to a number of different reasons including those that are pathological in nature. Fractures may result from pathologies and diseases such as osteoporosis and osteoarthritis, amongst a few. In such cases, damage is reduced by immobilization of the joint as movement gives rise to continued hyperaemic decalcification of the bone, which may lead to the disappearance of the entire femoral neck with time (Watson-Jones, 1936; Harty and Joyce, 1963; Gang *et al.*, 2010). Fractures to the femoral neck, may result in the blood supply being cut off to the head of the femur resulting in damage to the hip joint. Watson-Jones (1936) highlights three important clinical outcomes of this loss of blood supply to the head of the femur:

1. The loss of blood to the head of the femur may result in the slow union of intracapsular fractures of the neck of the femur, at the point where the neck of the femur joins the head.
2. Continued blood loss to the femoral head may bring about the sequel of osteoarthritis in the patient.
3. Loss of blood to the head of the femur may result in delayed treatment of ununited fractures, in which instances union to the different ends of the bone fails to occur. (Watson-Jones, 1936).

In trying to correct some of the problems caused by fractures to the neck of the femur, especially the slow union of the intracapsular fracture of the neck of the femur (at the point where the neck of the femur joins the head), Smith-Petersen (1931) created a nail that would immobilise the neck of the femur. The Smith-Petersen nail works to immobilise the area for four to six months or even longer, as this allows the femoral neck to unite (Smith-Petersen, 1931; Watson-Jones, 1936). In the article by Moore and Bohlman (1983), the pair also highlighted the use of the Moore nail in securing and immobilising the femoral neck (Moore and Bohlman, 1983).

Fractures of the neck of the femur are habitually followed by arthritis of the hip joint. This type of arthritis is a chronic autoimmune disease which is characterised by the inflammation of the joints and manifests in deformities. The chronic autoimmune disease is triggered by an unknown agent (possibly a virus) which causes an attack on the synovium by the immune system, resulting in the release of cytokines which stimulate an inflammatory reaction that can lead to the destruction of all components of the joint (Watson-Jones, 1936; Girdlestone 1982; Zwartelé *et al.*, 2012).

If the articular cartilage is deprived of blood for any length of time, it may undergo a degenerative change with resulting arthritis. It is therefore imperative in the instance where a fracture to the neck of the femur occurs, to completely immobilise the femoral neck so as to secure union of the fracture and minimize the period during which the blood supply of the articular cartilage is compromised (Watson-Jones, 1936). In occurrences where the blood supply to the head of the femur is retained even after femoral neck fracture, the nailing operation could be delayed and performed months later. The delay in immobilising the femoral neck remains the case unless there is reabsorption and shortening of the femoral neck, which could compromise good movement being regained (Watson-Jones, 1936; Harty and Joyce, 1963; Gang *et al.*, 2010).

In conclusion, it is imperative that injuries to the femoral neck are corrected in the shortest time possible, as further damage to the femoral neck might be prevented. Immobilisation of the femoral neck, which is usually the best possible outcome, would therefore prevent further damage to the hip joint.

3.3. The evolution of arthroplasty

Over the last three centuries, treatment of the hip related diseases has evolved from rudimentary surgery to modern day total hip arthroplasty (THA), which is considered one of the most successful surgical interventions ever developed (Gomez and Morcuende, 2005; Brown and Matta; 2008; Abdulkareem, 2013). Towards the end of the eighteenth century, the scope of orthopaedics had progressed as a result of identifying the physiology of the skeletal tissues, this phenomenon occurred during the first half of the 1800s (Gomez and Morcuende, 2005). The field of orthopaedics not only involves the minimally invasive (MIS) techniques to THA, but has also moved from making long incisions of about 20-30 cm to reducing them to as little as 5 cm, for cosmetic reasons (Pour *et al.*, 2005; Van Dijk *et al.*, 2009).

Prior to the introduction of hip arthroplasty, removal of the joints was practiced for a variety of joint diseases. Henry Park (1744-1831) a surgeon who worked in The Royal Infirmary of Liverpool in the United Kingdom, mentioned in a letter to the luminary of surgery and his teacher Percival Pott (1717-1788) his principles of treatment. Park (1782) mentioned the annulation of the articulation, or the entire removal of the extremities of all the bones which form the joints, with the whole or as much as possible of the capsular ligament, thereby obtaining a cure by means of a callus (Park, 1782; Gomez and Morcuende, 2005).

Even though a certain degree of joint excision was practised, it was seen as a less favourable option at the time due to the popularity of amputations amongst surgeons, and also due to the technical ease of amputations when compared with joint excision (Gomez and Morcuende, 2005). The process of performing amputations and invasive wound-healing procedures can be traced back to the Palaeolithic people, who administered these procedures in the years passed. In the years between 1700 and 1799 surgeons became more willing to perform amputations as well as complicated major organ surgeries. The surgeries performed were in the absence of anaesthesia. Anaesthesia only became available in the nineteenth century (Randolph, 2009). In the period leading up to the eighteenth-century, amputations were the most frequent surgeries performed with patients being held down by assistants in order to remove the troublesome limb. Amputators controlled bleeding and infection as best as they could and unique antiseptics were developed in order to prevent infection to the amputated limb (Randolph, 2009).

The first excision arthroplasty which was performed in 1821 is credited to Anthony White (1782-1849) of the Westminster Hospital in London. White was the first to give account of *phlegmasia albadens* (deep venous thrombosis in an extremity), which is a complication commonly associated with THA. This procedure improved pain and preserved mobility, at the expense of stability, therefore creating a need for an alternative form of treatment and possible cure (White, 1849; Gomez and Morcuende, 2005).

In 1826, the first osteotomy on the diseased hip joint was performed by John Rhea Barton (1794-1871) in Philadelphia. Barton is known as the originator of the corrective osteotomy for joint related diseases. He performed an intertrochanteric osteotomy without anaesthesia. After twenty days of the intertrochanteric osteotomy, he manipulated the extremity to provoke a fibrous reaction at the ends of the severed bone which was meant to initiate the healing process. Three months after the operation, the patient walked reasonably well with a cane, but six years later all mobility using the limb had been lost (White, 1849; Gomez and Morcuende, 2005;

Hernigou, 2013). During the intertrochanteric osteotomy, Barton first removed the femoral head, neck and trochanters. The patient survived the operation and lived for 12 years post-surgery. In his various attempts, Barton also performed a femoral osteotomy between the greater and lesser trochanters to secure motion in diseased hip joints. This femoral osteotomy has been called the first successful arthroplasty performed (Barton, 1827; Barton, 1837; Hernigou, 2013). Barton provided the first evidence that motion prevented bone fusion however, the patient in this operation eventually lost mobility (Barton 1827; Barton, 1837; Hernigou, 2013).

John Carnochan (1840) of New York, USA was the first surgeon who thought that the hip joint could be replaced. Carnochan inserted a wooden block between the damaged ends of a hip joint. Carnochan attempted to replace the parts of the joint that had worn off by experimenting with several biological and foreign materials. The different materials used included skin, fascia, muscle, pig bladder, and gold foil, all of which failed and proved to create much pain for the patients in whom these materials had been used (Ollier, 1885; Hernigou, 2013).

The evolution of hip arthroplasty ultimately led to interpositional arthroplasty. Interpositional arthroplasty is believed to have started in France by Auguste Stanislas Verneuil (1823-1895) from Paris France and Leopold Ollier (1830-1900). Interpositional arthroplasty entailed the replacement of the joint, through surgical correction. The abnormal stiffening and immobility of a joint due to fusion of the bones, was corrected by separation of the immobile part of a joint from the mobilised part by implanting a device between the articular components. Verneuil is said to have been the first to perform soft tissue hip interpositions in 1860; it was however Ollier's work that brought attention to the concept of interpositional arthroplasty (Ollier, 1885).

The experimentation with various interpositional materials was broadened by Vitezlav Chlumsky (1867-1943) of the Czech Republic. Chlumsky used materials which included muscles, celluloid, silver plates, rubber struts, magnesium (which resulted in the opposite effect of the desired results), zinc, glass, pyres, decalcified bone, and wax among others (Chlumsky 1896; Rang, 1966).

The attempt to find suitable material for interpositional arthroplasty was continued by Thermistocles Glück (1853-1942) of Berlin (Germany) who produced an ivory ball and socket joint in 1891, which he fixed to bone with nickel-plated screws (Glück, 1891; Rang, 1966). Glück steered the way in the development of hip implant fixation (Brand *et al.*, 2011). In his attempt at interpositional arthroplasty, Glück fixed the ends of a fractured femur with two steel

plates secured to the bone with screws. He was astonished at how early the injured limb could resume movement. During this period, Glück replaced a portion of a mandible resected due to cancer with a steel plate fixed to the bone with screws, which resulted in a positive outcome (Glück, 1891; Brand *et al.*, 2011).

Around 1890, several surgeons already had the insight that the free space left after the removal of the diseased joint might be filled with artificial material. One such surgeon was Nikolay Pirogov from Russia, who in 1830 proposed the replacement of a tuberculous knee with an artificial joint made of ivory. Glück was however the first surgeon to replace many tuberculous joints using artificial joints made from ivory. Remarkably, Glück designed and implanted artificial wrists, elbows, shoulders, hips, knees and ankles. In 1991, German orthopaedic surgeon Wessinghage traced 14 total joint replacements carried out by Glück during the 1880s that were described in Glück's publications (Glück, 1891). Wessinghage found that five of the replaced joint had retained function until 1891. Three of the replacements were total knee replacements, with one elbow and one total wrist replacement. All total joint replacements were made from ivory. Glück often used a special form of very hot "bone cement" that hardened within one minute for fixation inside the marrow cavity. In 1890 at the tenth international surgical congress in Berlin, Glück had a complete skeleton fitted with his various arthroplasties, which by now included the wrist, elbow, shoulder, ankle, hip and knee. The exhibited skeleton became famously known as the "skeleton of Paris" (Glück, 1891; Hernigou 2013). Although Glück's joint replacements were initially successful, they all ultimately failed because of chronic infection that occurred. A report of five cases was published, all tuberculous joints. Three of the prostheses were consequently removed, but one knee and one wrist replacement were left in place (Glück, 1891; Hernigou 2013). Nevertheless, Glück was the first to develop the idea of that foreign materials for total joint replacement must be well tolerated by the patient's body, a concept known as biocompatibility. Glück recognised that in order to achieve progress, experimental surgery was necessary, and the experimental surgeries were carried out on various animal species before replacements in human patients (Glück, 1891; Hernigou 2013). Glück is credited for introducing the term arthroplasty in 1902 (Rockwood *et al.*, 2004).

It is evident from the attempts and failure by various innovators that hip arthroplasty has evolved over the centuries, leading up to the current minimally invasive total hip arthroplasty methods. The ultimate goal of all innovators was to relieve the joint pain while increasing mobility in the diseased limb.

3.4. Failures in the attempt to find the perfect hip replacement material

In the attempt to find the perfect replacement component, various failures were encountered. Towards the end of the 19th century, John Benjamin Murphy (1857-1916) described the simple removal of bone osteophytes in order to correct the symptoms brought on by hip osteoarthritis (Murphy, 1915). Earlier in the 1900s, Murphy and Eric Lexer (1867-1937) from Germany had described hip interposition with special attention paid to the tensor fascia latae muscle (Lexer, 1908). A similar procedure was described by Henrich Helferich (1851-1945) for the treatment of the injuries relating to the temporo-mandibular joint (Helferich, 1894). In trying to find the perfect interpositional material, pig bladder was later suggested as a good interpositional material by a French surgeon known as Foedre (born 1860). Foedre had observed the strength of the pig bladder, suggesting it to be strong enough to withstand the stresses of mobilisation and joint pressures (Foedre, 1896).

The use of pig bladder as a replacement component was then popularised by William Steven Baer (1872-1931) in the USA (Baer, 1909; Baer, 1918), after the initial introduction of this material by Foedre. The contribution made by Baer in the orthopaedic world is significant, he is known for his contribution to the education of many frontrunners of orthopaedics (Le Vay, 1990). His students include, William Nachlas (1894-1958) who developed a shelf operation for dislocated hips (Nachlas, 1958; Le Vay, 1990). Harold Bohlman (1893-1979) a co-inventor of the Vitallium hip prosthesis, is also known to have been a student of Baer's (Bohlman, 1980; Le Vay, 1990). The list of luminaries include; Ralph K Ghormley (1893-1959), chief of orthopaedics and the Mayo Clinic in Rochester, Minn (Ghormley, 1959; Le Vay, 1990), and Guy W Leadbetter (1893-1945), who developed a reduction test for hip fractures (Leadbetter, 1946; Le Vay, 1990).

Other materials attempted include the use of gold foil. Robert Jones (1855-1933) used a strip of gold foil to cover the surface of the femoral head. In his report, twenty years after the surgery had been performed he alluded to the fact that the patient retained full mobilisation of the hip joint. Jones' report was the longest follow-up history to date (Jones and Lovett; 1929).

The use of the rubber femoral replacement component was first attempted by Pierre Delbet (1861-1925). Delbet used a rubber femoral prosthesis (1919) to perform a hemiarthroplasty (Judet and Judet, 1950). In 1927, Ernest Hey-Groves (1872-1944) experimented with ivory which resulted in catastrophic outcomes (Judet and Judet, 1950).

It is evident from the failures in the attempt to find the perfect interpositional material that the history of the replacement component in hip arthroplasty has been a tumultuous journey, at times leading to disastrous outcomes. The relentless attempts by various surgeons finally paid off with the discovery and current use of the various replacement materials. The materials used for modern day interpositional replacements currently include (but are not limited to); metal on metal replacements, metal on plastic, plastic on ceramic and ceramic on ceramic replacements.

3.5. Different approaches to hip arthroplasty

Numerous contributions have been made to the different approaches to hip arthroplasty in its current form. What is evident is that the categories of the different approaches to hip arthroplasty that we are familiar with, are built on foundations laid by many predecessors with modifications made to suite the surgeons need and specifications. These approaches are now categorised under the anterior, anterolateral, direct lateral, posterior and many adaptations of these approaches. For the purposes of this study, only the anterior approach and the anterolateral approach techniques are discussed in this section of the research.

3.5.1. The anterior approach

The anterior approach which is also called the iliofemoral approach is a procedure performed through a short anterior approach (Judet and Judet, 1950). The direct anterior approach was initially described by Hueter (1885), who looked through the interval between the tensor fascia latae and rectus femoris, this technique has been promoted above the other available techniques (Hueter, 1885; Myers and Leahy, 2008).

The anterior approach is used during the reduction of congenital dislocation of the hip, synovial biopsy, hemiarthroplasty, pelvic osteotomies, total hip replacement, joint drainage and irrigation of the joint during infection. The skin incision is made 2 cm lateral and inferior to the ASIS and extended distally and slightly laterally for 8-10 cm (Figure 3.1), ending 2 cm lateral to the greater trochanter (Smith-Petersen, 1949; Myers and Leahy, 2008; Onyemaechi *et al.*, 2014).

The Hueter technique was later modified in the United States to the now called Smith-Petersen technique (Smith-Petersen, 1949; Myers and Leahy, 2008).

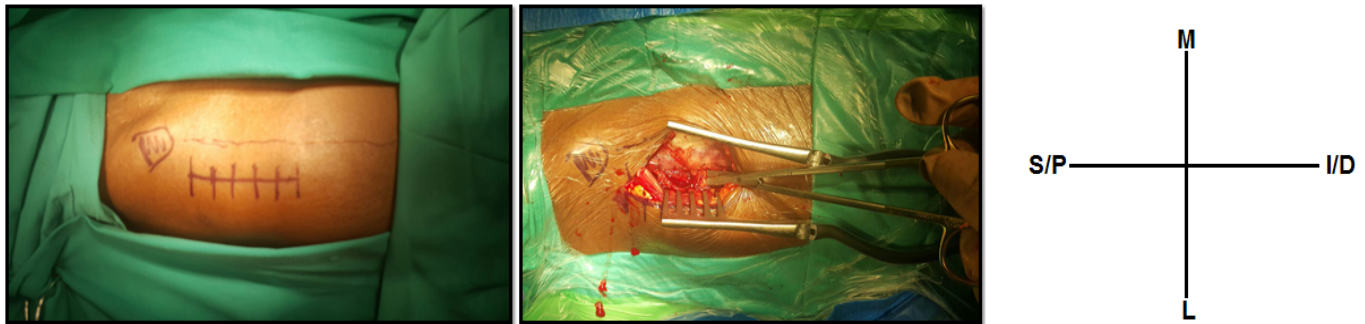


Figure 3.1: Anterolateral view of the thigh with the patient in a supine position. The incisions for the anterior approach were made 2 cm lateral and inferior to ASIS and 2 cm lateral to the greater trochanter. Key: *I-Inferior; D-Distal; M-Medial; L-Lateral; S-Superior; P-Proximal*.

3.5.2. The anterolateral approach

The anterolateral approach as initially described by Watson-Jones, is a procedure commonly used to resurfacing arthroplasty and primary THA. Dissection occurs between the gluteus maximus muscle and tensor fascia latae muscle superficially, and the gluteus medius and rectus femoris deeply (Watson-Jones, 1936; Mattingly, 1995). The anterolateral approach is an adaptation of the direct lateral approach initially described by Hardinge (1982), with modifications to the incision of the gluteus maximus. The direct lateral approach to the hip with the patient in a supine position offers the optimal conditions for orientation of the implant, cementation and correction of discrepancy in leg length (Hardinge, 1983).

The skin incision starts 2-3 cm posterior to the ASIS and is extended towards the mid portion of the greater trochanter. It then continues 10-15 cm along the axis of the femur (Figure 3.2). Incision of the tensor fascia latae muscle is made in line with the skin incision at the posterior aspect of the greater trochanter (Hardinge, 1983; Onyemaechi *et al.*, 2014).

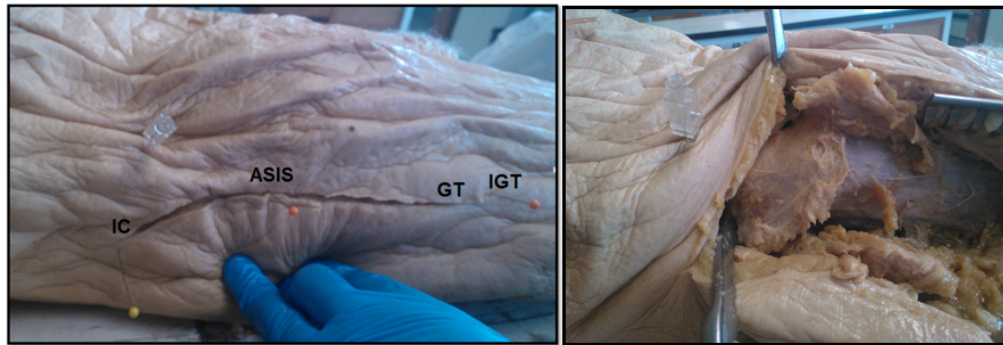


Figure 3.2: Lateral view of the thigh showing the cadaver in a supine position. Pins are used to indicate certain landmarks, namely: iliac crest (IC), ASIS, area inferior to greater trochanter (IGT). The incisions were made as per the anterolateral approach guidelines. *Key: I-Inferior; D-Distal; A-Anterior; P-Posterior; L-Lateral; S-Superior; P-Proximal.*

3.6. The contributors to hip arthroplasty

The advancement of total hip arthroplasty is a scope of medicine that has evolved since the 1800s, many surgeons have contributed to this field of research. The next section attempts to highlight a few of the luminary scholars associated with the different approaches to hip arthroplasty, and the eponyms given to the different approaches.

3.6.1. The von Langenbeck approach

The earliest record on the use of the posterior approach is that of Bernard von Langenbeck (1874). The operating procedure required the patient to lie on the unaffected side with the diseased hip flexed 45 degrees. The incision was made in the line along the greater trochanter. The incision was initiated at three finger-breadths proximal to the tip of the greater trochanter, and extended about three finger-breadths distally. The wound was then retracted and rotated (medially and laterally) in the attempt to facilitate detachment of the muscles and capsule from the trochanter and neck of the femur. The ligament of the head of the femur (ligamentum teres) was cut or torn across, and the head of the femur was dislocated from the acetabulum (Gibson, 1950).

3.6.2. The Hueter interval

The Hueter approach as initially described in his textbook in 1885, is now popularly known as the Smith-Petersen method (Hueter, 1885; Smith-Petersen, 1931; Smith-Petersen, 1949). The Hueter technique starts with the patient in a supine position. An incision is made distally which extends about 15 cm from the ASIS, passing between the sartorius muscle and the tensor fasciae latae muscle. The incision is then extended laterally to the rectus femoris muscle, the capsule of the hip joint is lastly exposed using blunt dissection (Hueter, 1883; Judet & Judet 1950).

Smaller incisions and decreased surgical trauma of the minimally invasive approach, have led to the popularity of the minimally invasive approach. The MIS has led to the slight modification of the Hueter technique over the years. The adaptation of the Hueter technique is performed with the patient in a supine position. The incision is initiated 2 cm lateral and posterior to the ASIS, extending 10 cm towards the greater trochanter (Hueter, 1885; Myers and Leahy, 2008).

3.6.3. Kocher's incision

The von Langenbeck approach was modified by Theodor Kocher (1907). The first edition of Kocher's "Operative Surgery" was published in 1892, but the earliest description of his approach to the hip joint was published in 1887. The ultimate goal of Kocher's incisions was to pass between nerves and therefore prevent damage to the neurovascular structures. In the attempt to access the hip joint, Kocher's incisions passed between the superior and inferior gluteal nerves and vessels by using the area between the gluteus medius muscle, gluteus minimus muscle and the tensor fasciae latae muscle. The incision which started from the greater trochanter was extended distally along the shaft of the femur (Gibson, 1950). The Kocher's and the von Langenbeck approach are the metaphors for the posterior or transgluteal approach.

3.6.4. The Smith-Petersen approach

Smith-Petersen is credited for spreading the anterior approach to hip arthroplasty in the English speaking world. His modification of the Hueter technique has been used in various treatments related to ailments of the hip joint (Gomez and Morcuende, 2005).

The anterior approach was popularised by Smith-Petersen by modifying the Hueter technique to his specifications (Gomez and Morcuende, 2005).

In 1923 Marius Smith-Petersen (1886-1953) from Boston Massachusetts suggested the use of synthetic interpositional arthroplasty with a mould prosthesis (Smith-Petersen, 1923). This device which was suggested by Smith-Petersen was designed to provide bone implant movements at two ends, the femoral and the acetabular ends (Smith-Petersen, 1923; Gomez and Morcuende, 2005). Smith-Petersen used the idea of interpositional hip arthroplasty initially devised by Ollier (1880) as a foundation of his research (Ollier, 1880).

The Smith-Petersen method starts off with the skin incision that extends from the middle and anterior thirds of the iliac crest to the ASIS, the incision is slightly lateral along the medial border of the tensor fasciae latae muscle (Smith-Petersen, 1949). The superficial fat and fascia are then incised and the area between the sartorius muscle and the tensor fasciae latae muscle is exposed by blunt dissection. In order to expose the anterior capsule of the hip joint, Smith-Petersen divided the deep iliac fascia and exposed the motor fibres of the femoral nerve. The joint is exposed by retraction of the iliopsoas muscle medially (Smith-Petersen, 1949).

3.6.5. The Whitman approach

Royal Whitman (1857-1946) used a reconstruction method as a way of treating *arthritis deformans*. In the operation, the head of the femur was removed and the trochanter cut from the shaft in an oblique direction. The trochanteric cut was made in a way that allowed all the muscles to remain attached to the bone. The additional area now obtained, was used as a surface which would allow the hip joint to securely bear weight. The newly constructed neck was inserted into the acetabulum. The leg was then abducted with the intention of implanting the reconstructed trochanter to the surface of the shaft (Figure 3.3). The ability of new articulation of the greater trochanter would be maintained by muscle tension. The reconstructed neck of the femur and the greater trochanter would allow the patient's limb to allow a range of movements which would enable the patient to walk and sit (Whitman, 1924).

The new operating technique is rooted in the operation performed by Groves (1923) which allowed the successful removal of the diseased bone (Whitman, 1924; Gomez and Morcuende, 2005). The disadvantage of this operating technique however, was in the manner the greater trochanter and the rim of the acetabulum were brought into direct contact with each other. The

result of this new articulation was limited abduction at the joint and visibly decreased mobility experienced by the patient (Whitman, 1924; Gomez and Morcuende, 2005).

As a result of the challenges noted with the technique by Grove (1923), Whitman (1924) came up with a criteria to be met for joint to gain functionality. Firstly, it was necessary to eliminate the progressive disability brought on by the disease. Secondly, the joint needed to sufficiently abduct and bear weight. Lastly, the operating procedure needed to restore a degree of voluntary movements at the joint (Whitman, 1924).

The disadvantage of the Whitman approach however, is seen in the tendency of the lower limb to move towards a flexed and adducted position. The Whitman approach required monitoring of the joint in order to prevent limb shortening (Whitman, 1924).

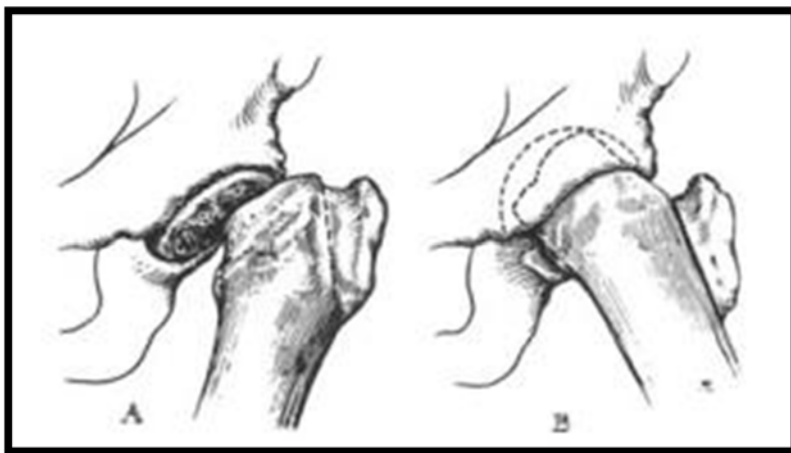


Figure 3.3: Whitman's reconstruction operation. In A, the line of division is shown on the trochanter which would allow the removal of the trochanter with all the abductor muscle intact. In B, the head of the femur is removed and the greater trochanter secured on the shaft of the femur (Ollier, 1892).

3.6.6. Other revolutionary approaches

Gathorne Girdlestone (1881-1950), from Oxford in the United Kingdom reintroduced the removal of the femoral head when tuberculosis was discovered in the bone (Girdlestone, 1943). The Girdlestone approach is still used by some surgeons as a last resort after failed THA. The

Girdlestone approach is also known as conversion arthroplasty (Girdlestone, 1943; Seddon, 2004).

Frederick Thomas (1907-1983) from the USA, later modified the idea of the Judet brothers by producing a Vitallium prosthesis in the 1950s (Judet and Judet, 1950). Thomas (1940), collaborated with Harold Bohlman (1893-1979) from Nebraska, and Austin Moore (1899-1963). The collaboration by Thomas, Bohlman and Moore resulted in the first of this prosthesis being implanted in 1940. The prosthesis was later modified by Bohlman and Moore (Moore and Bohlman, 1943). In 1952, these prosthesis implants were still used in hemiarthroplasty after the neck of femur had fractured (Moore and Bohlman, 1943; Thompson, 1952).

In 1938, the first hip replacement fitted with stainless steel component was introduced by Philip Wiles (1899-1966) of the Middlesex hospital in London. Wiles used the stainless steel components to fix the bone with screws and bolts. The outcome of the experiment by Wiles did not yield the desired outcome (Wiles, 1957).

In the 1940s, Edward Haboush (1904-1973) from USA and Kenneth McKee (1905-1991) from Norwich England developed prostheses. This set of prosthesis made use of the acrylic dental cement for fixation of the implantation device in the bone (McKee and Watson-Farrar, 1966).

In 1964, Peter Ring (born 1922) from Britain attempted the use of cement-less prosthesis with metal-on-metal articulation. The implantation devices used by Ring had good outcomes, lasting for up to seventeen years or more (Ring, 1971). The prosthetic devices created by Ring, were later abandoned for the Charnley models (Ring, 1971).

3.6.7. The Gibson technique of operation

Alexander Gibson along with Austin Moore, are known as the surgeons who popularised the posterior approach (Gibson, 1950). In the Gibson operation procedure, the patient is placed on the unaffected side. The Gibson technique only required the palpation of the posterior superior iliac spine and the anterior aspect of the greater trochanter. The operating procedure entails the division of the gluteal fascia along the upper border of the gluteus maximus muscle, in the attempt to gain access to the hip joint (Gibson, 1950).

The muscles are then detached from the greater trochanter according to innervation. The muscle innervated by the superior gluteal nerve are retracted anteriorly while the other muscles

are retracted posteriorly. The Gibson technique requires the detachment of the gluteus medius muscle from the greater trochanter. The piriformis muscle is also retracted in the attempt to expose the capsule surrounding the hip joint (Gibson, 1950).

3.6.8. The Charnley method

Sir John Charnley worked in Manchester Royal Infirmary, is considered the father of modern THAs (Charnley, 1961). The concept of low friction arthroplasty was introduced by Charnley in the 1960s (Charnley, 1960). The concept of low friction arthroplasty consisted of a metal femoral stem which had a small head to reduce the rate of wear on the weight bearing surface (Charnley, 1960; Charnley, 1961).

In the method used by Charnley, the patient was positioned on the side of the healthy limb. The incision was made as per the direct lateral approach. The gateway to the hip joint was through the tensor fasciae latae muscle, which was divided 2-3 cm distally to the greater trochanter. The incision was then extended by curving it proximally, parallel to the gluteus maximus muscle. The anterior capsule of the hip joint was then exposed and then divided to expose the fold of the vastus lateralis muscle (Charnley, 1960; Charnley; 1979).

3.6.9. The Hardinge technique

The Hardinge direct lateral approach to hip replacement is a modified version of the technique described by McFarland and Osborne in 1954. In their observation, McFarland and Osborne based their method upon the attachment of gluteus medius and vastus lateralis where functionally, they are continuous through the thick tendinous periosteum covering the greater trochanter. In the method described by McFarland and Osborne, a thin shell of bone from the lateral aspect of the trochanter would be removed as part of the replacement process. The procedure also required the patient to be on his unaffected side, which sometimes creates some difficulties. The challenges encountered by the patient laying on the side is in the orientating the implantation device and in the correction of the difference in leg length (McFarland and Osborne, 1954; Hardinge, 1982).

The skin incision is made in a way that allows the greater trochanter to be the midpoint. The incision is then extended parallel to the shaft of the femur along the anterior border, this

extension is about 8 cm. The incision is followed until it terminates posteriorly at the level of the ASIS. The gluteal fascia and iliotibial band is exposed and division made along the midlateral line. The capsule of the hip joint is exposed by retraction of the tensor fascia latae muscle anteriorly and the gluteus maximus (Hardinge, 1983).

The transformation and adaptation of the various surgical procedures have led to the innovation of the MIS procedure to hip arthroplasty. Various surgeons, in their attempt to do what is best for the patient, have adapted their techniques and even moved from techniques they may have been previously comfortable with to those indicated to show better outcomes. The foundation laid over the years has resulted in the move towards MIS THA.

3.7. Modern day hip arthroplasty

Hip arthroplasty in its current form has changed drastically over the years. Many contributors are credited for the modern approaches used in total hip arthroplasty. MIS THA as it is now known, encompasses a variety of approaches in the attempt to access the hip joint. In the following sections, MIS THA will be discussed along with computer aided THA, a new concept that is gaining interest.

3.7.1. Minimally invasive approach to total hip arthroplasty

The idea of MIS THA was aimed at potentially decreasing the amount of pain associated with hip arthroplasty (Rachbauer, 2006). The attraction of the new concept saw the decrease in the overall trauma to soft tissue and blood loss during surgery, while attempting to accelerate rehabilitation (Berger *et al.*, 2004; Duwelius and Dorr, 2007)

For a hip replacement procedure to be classified as minimally invasive, it is essential that the procedure be performed with minimal soft tissue disturbance (Nakata *et al.*, 2009; Gang *et al.*, 2010; Moskal *et al.*, 2014).

The minimal anterior approach was first described by Smith-Petersen from his adaptation of the anterior Hueter approach (Hueter, 1885; Judet, 1947; Smith-Petersen, 1949). This approach entails accessing the hip joint through the intermuscular space between the tensor fascia latae muscle and the rectus femoris muscles (Hueter, 1885; Smith-Petersen, 1949).

One of the advantages of specifically minimally invasive anterior approach is that since no muscle or tendons are sectioned in order to gain access to the hip joint for prosthesis implantation, lower dislocation rates are noted (Mattingly, 1995; Siguier *et al.*, 2004; Matta *et al.*, 2005; Lowell, 2008). Smaller skin incisions are also made which ensures that less blood is lost and the postoperative pain is reduced (Berger *et al.*, 2004; Dorr, Maheshwari and Long, 2007).

The advantage of the MIS technique is that once the learning curve is achieved, minimally invasive procedure does not increase operating time. It was also observed that MIS was not associated with increased complications. MIS is noted for a decrease in component malposition when compared with the traditional techniques (Reininga *et al.*, 2010).

Similar results were published when the anterior approach was used, which resulted in more accurate implantation of the prostheses and also spared the need for extra assistants in the operation therefore, leading to savings in the cost of surgery (Mark *et al.*, 2011; Gebel *et al.*, 2012).

3.7.2. Computer aided THA

Computer aided THA has also being introduced and is currently tried in many centres across the world (Abdulkareem, 2013). Computer aided THA involves the use of computers for navigating the cup and stem placement. The use of this method is achieved by often combining computer aided THA with the MIS. Sufficient amount of training is necessary for the surgeon to be skilled in the use of this innovative surgical procedure.

The popularity associated with computer aided surgery for hip replacements, is due to the accuracy of this method in implant placement. The advantage associated with computed aided surgeries is the noticeable decrease in the rate of post-operative complication, such as dislocations of the hip joint (Reininga *et al.*, 2010).

Sugano (2013) highlights another innovation in computer aided surgeries. The use of an active robotic system (ROBODOC) during computer aided surgeries, revealed better stem alignment and decreased incidence of pulmonary embolism (Sugano, 2013).

It is evident from the strides made over the years in the field of orthopaedics, that the ultimate goal of the surgical procedures are an attempt at better patient outcomes. The goal has also

moved, to include a reduced period of hospital stay and cost of the surgical procedures to the patient and the health care system.

Chapter 4

Materials and Methods

Each of the approaches to hip arthroplasty has merits that indicate that they are both beneficial for patient outcome (Mattingly, 1995; Van Dijk *et al.*, 2009). The methods described in this chapter are for the anterior and anterolateral approaches due to the increasing popularity of the anterior approach in hip arthroplasty (Lovell, 2008). The comparison of the anterior and the anterolateral approach is done in order to determine whether any damage might occur to the neurovascular structures (LCFA and LFCN) when the anterior or anterolateral approaches are used during hip arthroplasty. Simulations of the incisions made during the anterior approach were performed on the cadavers by an orthopaedic surgeon, and the area around them dissected.

4.1. Materials

For this study, a descriptive cross-sectional, observational, quantitative approach was taken in an attempt to further investigate the comparative anatomy of the anterior and anterolateral approaches to hip arthroplasty. Ten hips were initially dissected for the pilot study to assess the difficulty of this procedure, and the factors constituting ‘level of damage’ when this procedure is used. The level of damage was determined by factors that looked at whether the muscles and neurovascular structures would or could be mutilated in the attempt to access the anterior capsule of the hip joint. Eighty hips were subsequently dissected after the completion of the pilot study, bringing the total number of hips dissected to 90 for the anterior approach. Difficulty was encountered in certain instances where the nerve (LFCN) and/or the artery (LCFA) had been removed and only one limb could be used, resulting in the number of cadavers dissected being more than the anticipated 40. Twenty hips were dissected for the anterolateral approach, due to the limited number of cadaver material, and 21 hips) with the assistance of an orthopaedic surgeon to perform a proper simulation of the anterior approach, and one complete hip replacement on the cadaver. The incision made by the orthopaedic surgeon included one anterolateral approach dissection, on the cadaver previously dissected for the anterior approach. The cadavers (of various ages) were obtained from the University of Pretoria, Department of Anatomy. This sample consisted of both male (n=70) and female (n=16) cadavers of different ancestry groups and varying body mass index (BMI). The height and weight were included in the data capturing process where data was available. It was

anticipated that these measurements might affect the distance of the lateral femoral cutaneous nerve (LFCN) and lateral circumflex femoral artery (LCFA) to the anatomical landmarks. The measurements for the anterior approach were taken in relation to the anterior superior iliac spine (ASIS) and the pubic tubercle, which served as the anatomical landmarks to which the LFCN and LCFA are referenced in relation to. A sliding calliper (accuracy of 0.02 mm) was used to measure the distance between the LFCN and the LCFA to the ASIS, pubic tubercle and the anterior capsule of the hip joint. The anterior capsule of the hip joint was measured on the middle third of the lateral border of the iliopsoas muscle as it is seen in the anterior compartment of the thigh. The iliopsoas, as observed in the anterior compartment of the thigh, was divided through imaginary lines into three equal parts after it appears at the inferior border of the inguinal ligament (Figure 4.1a and 4.1b).

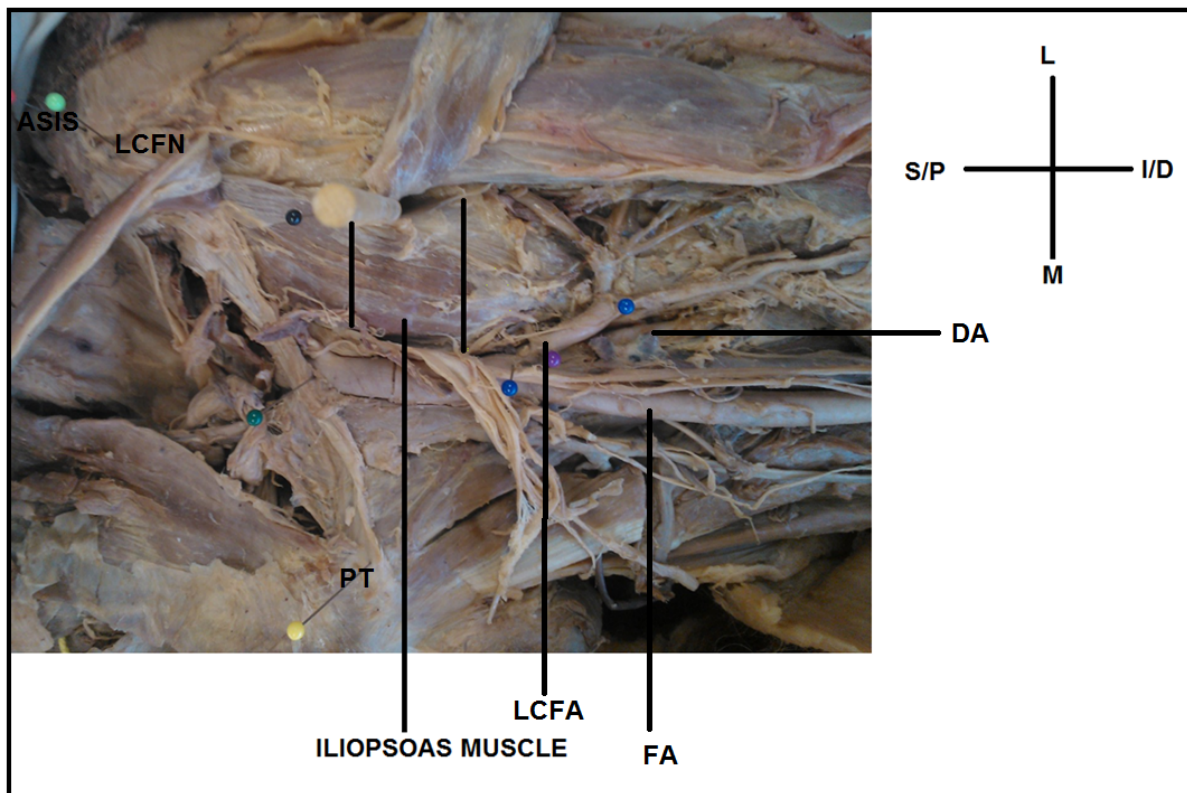


Figure 4.1a: Anterior view of the thigh showing the iliopsoas muscle as it is seen in the anterior compartment of the thigh. The muscle is divided into three equal parts through imaginary lines. Key: I-Inferior; D-Distal; M-Medial; L-Lateral; S/P-Superior, Proximal; A-Anterior; P-Posterior; FA-Femoral Artery; DA-Profunda femoris artery; PT-Pubic Tubercle.

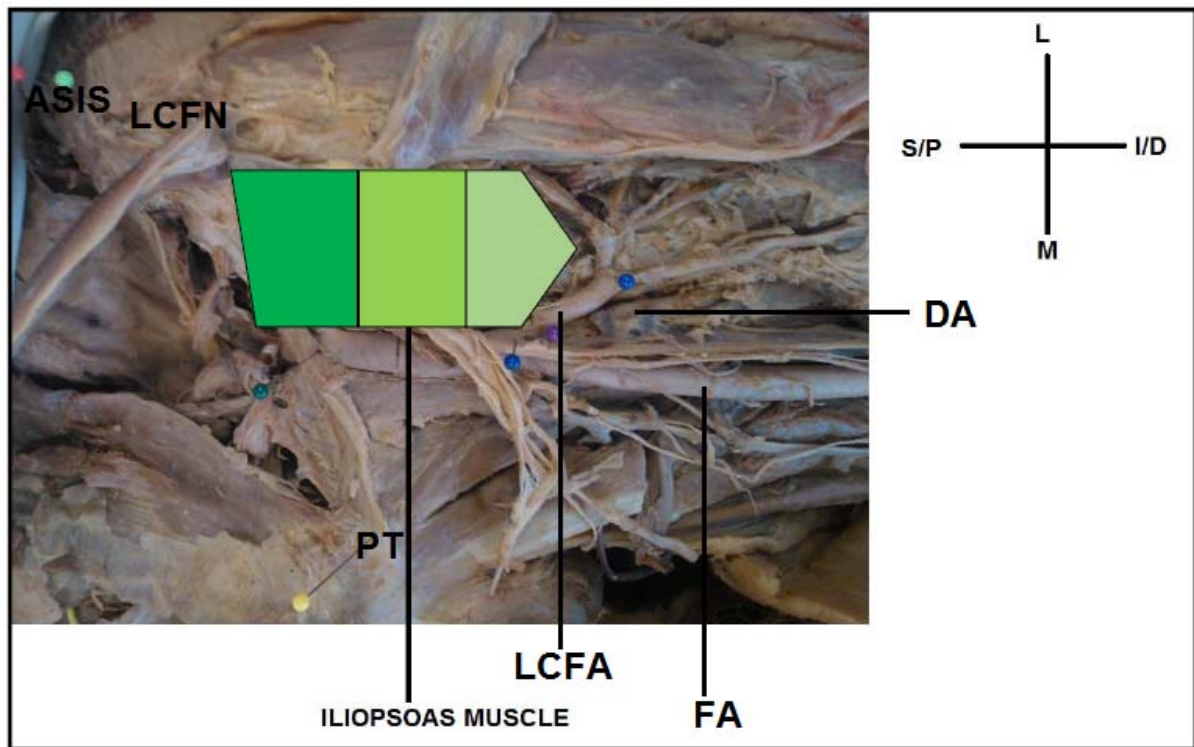


Figure 4.1b: Anterior view of the thigh showing the iliopsoas muscle as it is seen in the anterior compartment of the thigh, posterior to the inguinal ligament. The muscle is divided into three equal parts through imaginary lines. Key: *I-Inferior; D-Distal; M-Medial; L-Lateral; S/P-Superior, Proximal; A-Anterior; P-Posterior; FA-Femoral Artery; DA-Profunda femoris artery; PT-Pubic Tubercle.*

4.2. Inclusion criteria

The study included male (n=70) and female (n=16) cadavers of various BMI (range of $\pm 18 - 30 \text{ kg/m}^2$) due to the limited number of cadavers with normal BMI (range of $\pm 18 - 25 \text{ kg/m}^2$). BMI was calculated from a cadaver's weight and height by dividing the weight (in kilograms) by the height (in meters) squared. The sample size consisted of cadavers of different ancestry groups, as variations in the course of the LFCN and the LCFA, based on ancestry, were not anticipated. The height and weight measurements of some cadavers were not available and could therefore not be included in the final analysis process. The cadavers in whom the height and weight measurements were unavailable, were dissected to collect data on the distances between the bony landmarks and the LFCN and LCFA for the anterior approach, as well as distances from the bony landmarks to the superior gluteal vessels for the anterolateral approach.

4.3. Exclusion criteria

Cadavers which had any trauma in the hip joint region were excluded, as well as cadavers bearing any visible scars in the anterior thigh compartment, due to possible previous surgery.

The exclusion criteria also applied to those cadavers which had hip arthroplasty performed through the posterior approach, as the joint capsule would have been disturbed. Such cadavers were, however, not found in the sample used for this study. The exclusion criteria also took into account those cadavers on which the femoral artery, profunda femoris artery or the LCFA has been transected or removed by previous dissectors. A number of cadavers still had the LFCN intact but the femoral artery had been removed or transected. Due to a shortage of cadavers, the other limb, which was still intact was included in the study. In two cadavers the LCFA had been transected on the left side but the right side was still intact. The right side measurements of the same cadavers were included as part of the data collected.

The last category consisted of cadavers on which the LFCN had been removed by students who had worked on the cadavers in the abdominal region, even though the LCFA was still intact. A number of these cases were encountered: seven LFCNs had been removed on the left side with the right side uninterrupted, and five LFCNs had been removed on the right side with the left side uninterrupted. Data was therefore collected on the right side of the seven cadavers where the LFCNs had been removed, and on the left side of the five cadavers on whom the LFCNs had been removed, these measurements were added to the collection.

4.4. Ethical consideration

Ethical clearance for this study was sought and obtained from the Faculty of Health Sciences Research Ethics Committee, University of Pretoria (Protocol number: 274/2014) prior to the commencement of the data collection phase of this study. All the adult cadavers used in this study were obtained and dissected under the rules and regulations defined within the South African National Health Act 61 of 2003. All data was collected from full body cadavers. The cadavers were handled with respect and care at all times, and properly safeguarded. No information which could possibly reveal the identities of the cadavers was obtained.

Access to personal information regarding the cadaver's age, height and weight was noted, and restricted to the author. No other personal information was obtained. All information was, and will be kept confidential for 15 years as required by the regulations of the Research ethics Committee, Faculty of Health Sciences, University of Pretoria.

4.5. Statistics

Standard descriptive statistics (including means, standard error, 95% CI) were calculated per age group, sex, BMI, height and weight ranges. An analysis of variance (ANOVA) was used to assess differences in measurements from the various anatomical landmarks to the soft tissue between different age groups, sexes, BMI ranges, height and weight ranges. Results from the current study were compared to results from other studies regarding distance from the various anatomical landmarks to the soft tissue discussed. Details of these comparisons are provided in sections 5.4 – 5.8.

4.6. Pilot study

A pilot study was conducted to firstly determine the agreement rating of the dissection method between two different dissectors. The agreement rating is important for ascertaining whether the methods described in the research can be replicated resulting in a similar outcome. As far as what could be determined no gold standard is available to define what constitutes “level of damage” to the nerve (LFCN). In practical terms the distance of the surgical simulation incision to the LFCN and the LCFA is for a mean distance ± 1 SD will be useful to determine a “safe” area around the nerve.

The pilot study involved the dissection of five cadavers (both left and right lower limbs) of various BMI (excluding obese cadavers of BMI 30 kg/m² and above). This study also included/investigated the possible proportion of damage to the LFCN and any of its branches. The level of damage to the cadaver, was also assessed (in the attempt to access the anterior capsule of the hip joint). As no set method is available for hip arthroplasty using the anterior and anterolateral approach when using cadaver material, the attempt was to also develop a standard method for these dissections.

In the pilot study it was noted that, the distance of the LFCN from the ASIS where it exits behind the inguinal ligament, varies from 6 to 23 mm on the left side and 4 to 29 mm on the right side. The study also showed numerous variations in the anatomy of the LCFA. In some cases the LCFA branches directly from the femoral artery, with the transverse branch mostly originating from the ascending branch. LCFA sometimes gave off a “collateral” descending branch instead of one descending branch (Figure 4.2). Clear variations were also seen on the left and right in the branching pattern of the LCFA. The transverse branch was not always present, but the descending branch sometimes gave off the transverse branch.

The pilot study confirmed that the anterior and anterolateral approaches allow easy access to the anterior capsule of the hip joint. Visualisation can be improved with a retractor on live specimens. The ascending branch of LCFA also serves as a guideline in accessing the anterior capsule of the hip joint.

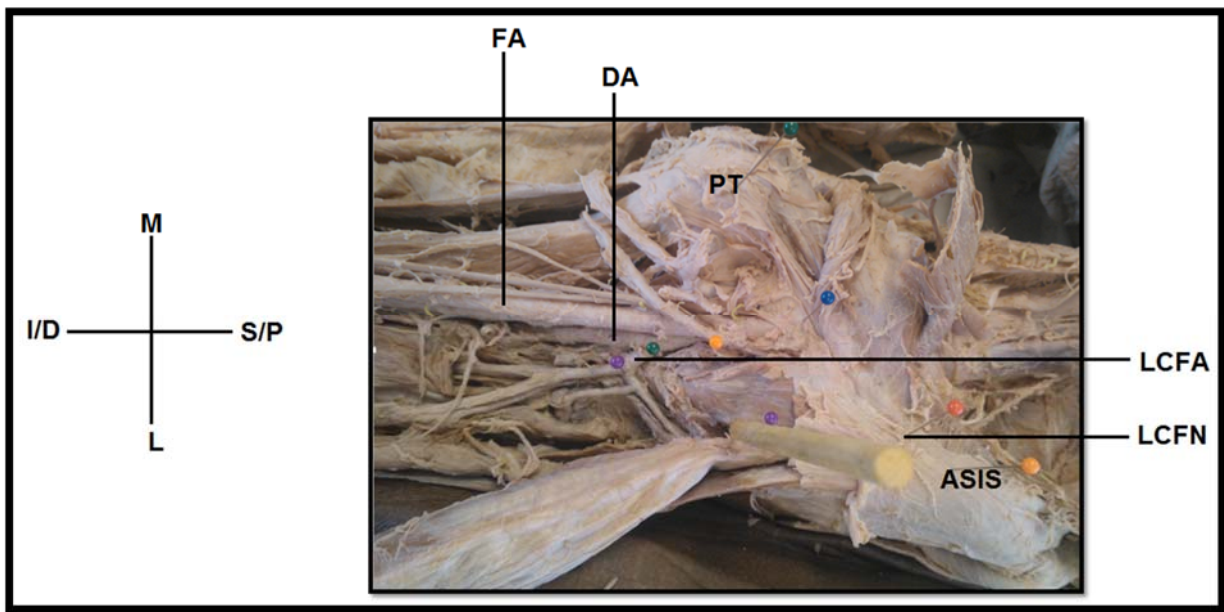


Figure 4.2: Anterior view of the thigh showing the femoral artery, profunda femoris artery, and the LCFA giving off “collateral” descending branches from the descending branch and the ascending branch of the LCFA. Key: *I-Inferior; D-Distal; M-Medial; L-Lateral; S/P-Superior, Proximal; A-Anterior; P-Posterior; FA-Femoral Artery; DA-Profunda femoris artery; PT-Pubic Tubercle.*

4.7. Methods

A simulation of the anterior and anterolateral approaches to hip surgery was performed on cadaver material. The incision and transecting of the muscles were performed by the primary investigator. These simulations and subsequent dissections are further discussed in section 4.7.2 and 4.7.3. Cadavers were used with the aim of exposing the relevant anatomy for the anterior and anterolateral approaches, as well as highlighting the structures that may be in danger with these approaches and possibly expanding on the literature currently available. The advantage of using cadaver material was that it enabled the expansion of the exploratory incision by the primary investigator. As a result, the joint could be exposed and the LFCN

could be visualised along with the distribution of its branches (Figure 4.3a and 4.3b). The sartorius muscle and the rectus femoris muscle could also be transected for better access to the hip joint. In living persons however, the muscles are retracted, which is not possible when using cadaver material due to its fixed and hardened state.

The data for the anterior and the anterolateral approach was collected with the cadaver in a supine position with the iliac crest, pubic tubercle, ASIS, medial condyle, lateral condyle as other anatomical landmarks, easily palpable (Figure 4.3a). A complete discussion of the data collection can be found in section 4.7.1, 4.7.2 and 4.7.3.

4.7.1. The anterior approach

The anterior approach as described in this section of literature varies from the methods as defined and discussed in published articles. The variation in the methods is due to the use of cadavers, which are fixed and not as pliable as what would be encountered in the operating theatre. The incisions made and the muscles transected are in order to access the anterior capsule of the hip joint. Various structures, such as the LCFA and LFCN, and the variations of these structures encountered *en route* to the anterior capsule of the hip joint are noted and discussed in the later chapters of this study.

Three incisions were made as represented by numbers 1, 2 and 3 in Figures 4.3a and 4.3b

1. An incision was made from a point about 2 cm lateral and 1 cm superior to the ASIS. This incision extended from the area around ASIS to the pubic tubercle in undissected cadavers. The incision allowed for the exposure of the inguinal ligament. This was important for identifying the LFCN as it becomes visible inferior to the inguinal ligament. The length of the incision depended on cadaver size, subcutaneous fat, and/or muscle mass.
2. An imaginary line was drawn from a point 2 cm lateral to the ASIS along the skin overlying the tensor fascia latae muscle, to the lateral condyle of the femur. A second incision was then made along this line.
3. The third incision was made from the lateral condyle to the medial condyle of the femur, with the intention of fully exposing the quadriceps femoris muscle and studying the distribution of the branches of LFCN. These branches, their course and variations in their branching would

be important for the orthopaedic surgeon to be aware of, as injury to the LFCN branches may cause thigh numbness after surgery. The LFCN exits the pelvis and then sends branches medially across the sartorius muscle, 2 to 3 cm distal to the ASIS (Moore and Dalley, 1999). For the purpose of this study, it is necessary to identify the inguinal ligament, as the LFCN passes deep to the inguinal ligament before it can be identified over the sartorius muscle (Figure 4.3b).



Figure 4.3a: Anterior view of the thigh showing the imaginary lines along which the incisions made. The first incision (1) is made from the PT to the ASIS, the second incision (2) is made on a line connecting ASIS to the LC. The last incision (3) is made from the LC to MC. Key: *I-Inferior; D-Distal; M-Medial; L-Lateral; S/P-Superior, Proximal; A-Anterior; P-Posterior; PT-Pubic Tubercle; MC-Medial Condyle of the Femur; LC-Lateral Condyle of the Femur.*



Figure 4.3b: Anterior view of the thigh showing the anatomical landmarks to be palpated before the skin is reflected. These include the pubic tubercle, medial condyle, lateral condyle and the ASIS. Key: *I-Inferior; D-Distal; M-Medial; L-Lateral; S/P-Superior, Proximal; PT-Pubic Tubercle; MC-Medial Condyle of the Femur; LC-Lateral Condyle of the Femur; IL-Inguinal Ligament.*

From the dissections made during the data collecting stage of this study it was also noted that the LFCN, after it exits inferior to the inguinal ligament, travels medially within the iliotibial band until its branches can be seen running across the sartorius muscle.

The skin overlying the ASIS and part of the iliac crest, tensor fascia latae muscle and the LFCN were carefully dissected and reflected medially, to expose the subcutaneous fat and superficial vessels. Care was taken not to damage any veins or other superficial nerves and their branches in this region, while attempting to gain access to the anterior capsule of the hip joint. It was noted that if the orthopaedic surgeon accessed the anterior capsule of the hip joint in the manner described in current literature (Kennon *et al.*, 2004; Lovell, 2008), no other major vessels (such as the ascending branch of the LCFA) will be injured as these are clearly visible and can easily be avoided. Any variations of the normal regional anatomy were also noted and will be discussed in the results.

The subcutaneous fat was removed until the thin, translucent fascia overlying the tensor fascia latae muscle was exposed. The fascia was then teased out using a finger to isolate the tensor laterally, slipping into the interval between the superior femoral neck and the abductors (Bal, 2008). The tensor fascia latae muscle (H) was identified and split along its anterior margin to expose the LFCN and trace it back to its relation to ASIS and the inguinal ligament. The thin

strip of muscle and fascia left medially, protects the lateral femoral cutaneous nerve (G) and allows better wound closure (Kennon *et al.*, 2004; Üzel *et al.*, 2011). The nerve, along with its branches, was identified in its course as it passes behind the inguinal ligament and becomes visible medial to the ASIS. The branches were followed and dissected out before the fascia was cleaned, so as not to damage the nerve before exposing the underlying muscles. The course and number of branches were noted as they remain an area of concern for injury during hip arthroplasty.

The subcutaneous fat was then dissected more medially until the translucent fascia overlying sartorius muscle and the quadriceps femoris muscle was clearly visible. The fascia was then dissected and the sartorius muscle and the quadriceps femoris muscle separated by blunt dissection to expose the LCFA (I). The sartorius muscle (J) was transected (Figure 4.4b). This allowed better access to the anterior capsule of the hip joint and the LCFA. The rectus femoris muscle (K) was transected its straight head elevated from the underlying capsule by blunt or sharp dissection.



Figure 4.4a: A deeper dissection of the anterior compartment of the thigh showing the straight head of rectus femoris and sartorius muscles along with the tensor fascia latae muscle with the iliotibial band removed. The lateral circumflex femoral artery (I) is clearly visible. Key: I-Inferior; D-Distal; M-Medial; L-Lateral; S-Superior; P-Proximal.

The surgical method used when applying the anterior approach to THA can be done through a short incision. It is possible to extend it distally along the femur, or along the anterior iliac

crest. This incision is usually as short as possible but as long as necessary. The results of the anterior approach are not affected by a slightly longer skin incision but can be compromised by unnecessarily short incisions (Keggi and Rubin, 2008). The cadaver incision however, is made longer to allow for clear visualisation of the tensor fascia latae, the LFCN, the LCFA as well as easy access to the anterior capsule of the hip joint. The difficulty in accessing the anterior capsule of the hip joint when either method is used was noted, as well as the possible structural damage that might occur when either method is used. Coloured pins were used to mark the following areas (Figures 4a and 4b):

- The pubic tubercle (point A)
- The medial condyle of the femur (point B)
- The lateral condyle of the femur (point C)
- The anterior superior iliac spine (point D)
- The anterior capsule of the hip joint (point F)
- The lateral femoral cutaneous nerve (point G)
- The lateral circumflex femoral artery (point I)
- The branching of the lateral circumflex femoral artery (I) into the ascending, descending and transverse branches.
- The proximal part of the femoral artery.
- The origin of the profunda femoris artery/ profunda femoris artery.
- The ascending branch of the LCFA giving off a transverse branch.

The following distances were measured (Figures 4a and 4b):

- The distance from the pubic tubercle (A) to the anterior capsule of the hip joint (F).
- The shortest distance from the pubic tubercle (A) to the lateral femoral cutaneous nerve (G).
- The distance from the pubic tubercle (A) to the lateral circumflex femoral artery (I).
- The shortest distance from ASIS (D) to the lateral femoral cutaneous nerve (G).
- The shortest distance from the anterior capsule of the hip joint (F) to the lateral femoral cutaneous nerve (G).
- The distance from the anterior capsule of the hip joint (F) to the lateral circumflex femoral artery (I).

- The distance from the anterior capsule of the hip joint (F) to where the lateral circumflex femoral artery (I₃) branches into the ascending and descending branches.
- The thickness of the straight and straight head of rectus femoris muscle (K).
- The distance from the pubic tubercle (A) to the medial boundary of the head of rectus femoris muscle (K).
- The distance from where the femoral artery is first visualised exiting behind the inguinal ligament to where it gives off the profunda femoris artery.
- The distance from where the profunda femoris artery gives off the LCFA (I).
- The distance from, the origin of the LCFA (I) from the profunda femoris artery, to where it gives off an ascending, descending and/or transverse branch.
- The distance from LCFA (I) branching into ascending, descending and/or transverse branch to where the ascending and/or descending gives off a transverse branch.

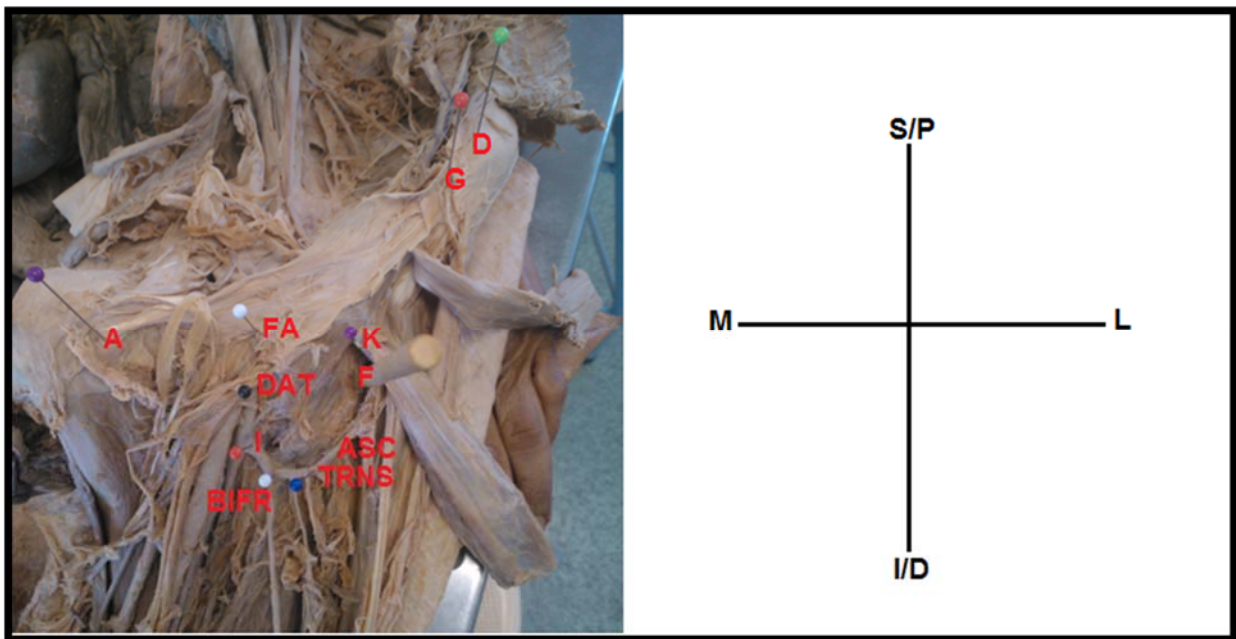


Figure 4.4b: A deeper dissection of the anterior compartment of the thigh showing the distances measured in relation to the pubic tubercle, ASIS, LCFA, LFCN and the anterior capsule of the hip joint. Key: *I-Inferior; D-Distal; M-Medial; L-Lateral; S-Superior; P-Proximal*.

4.7.2. The anterolateral approach

The cadaver was in a supine position with all the anatomical landmarks easily palpable. The anatomical landmarks that had to be palpated before making incisions were the ASIS, greater trochanter, the most lateral aspect of the patella and the iliac crest.

The incision was made just anterior to the centre of the greater trochanter and was curved into the posterior aspect of the buttock (Figure 4.5). The skin incision was then extended to the iliac crest, the anterior compartment of the thigh as well as the gluteal area, to allow for better visualisation of the joint. The recommended length of the incision in live patients is 20-30 cm from the iliac crest to the area just distal to the greater trochanter (van Dijk *et al.*, 2009). Two thirds of this incision is proximal, and one third distal to the tip of the greater trochanter (van Dijk *et al.*, 2009). The fascia was incised centrally or posterior to the tip of the greater trochanter. The abductor mechanism was released in order to expose the capsule of the hip (van Dijk *et al.*, 2009). Therefore, the incision will include cutting through gluteus maximus muscle and the tensor fascia latae muscle. The gluteus maximus muscle was transected and reflected and the anterior 1/3 of the gluteus medius muscle also incised. This allowed better exposure and access to the joint capsule. The area superior to the greater trochanter was dissected until the superior gluteal vessels were identified and pinned, as these are structures of concern during the anterolateral approach.

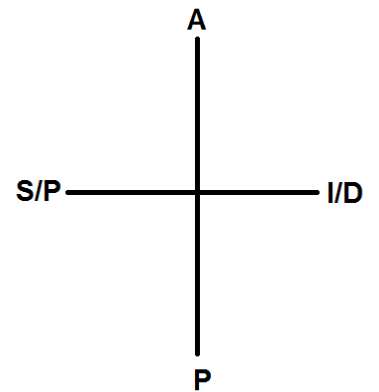
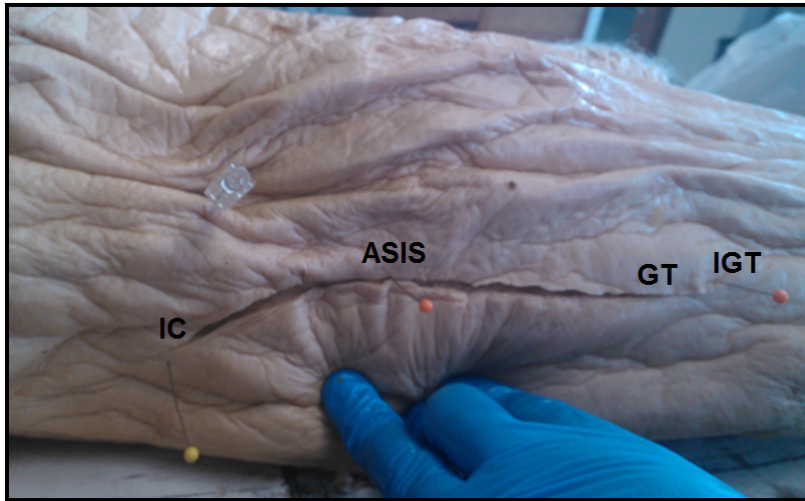


Figure 4.5: Lateral view of the thigh showing the cadaver in a supine position. Pins are used to indicate certain landmarks, namely: iliac crest (IC), ASIS, area inferior to greater trochanter (IGT). *I-Inferior; D-Distal; M-Medial; L-Lateral; S/P-Superior, Proximal; A-Anterior; P-Posterior; GT-Greater Trochanter; IGT-Inferior to Greater Trochanter.*

Coloured pins were used to mark the following landmarks and areas in order to make accurate incisions (Figures 4.6, 4.7 and 4.8):

The anterior superior iliac spine (J), greater trochanter (K), the most lateral aspect of the patella (L), superior gluteal vessels (M), and the joint capsule (N).

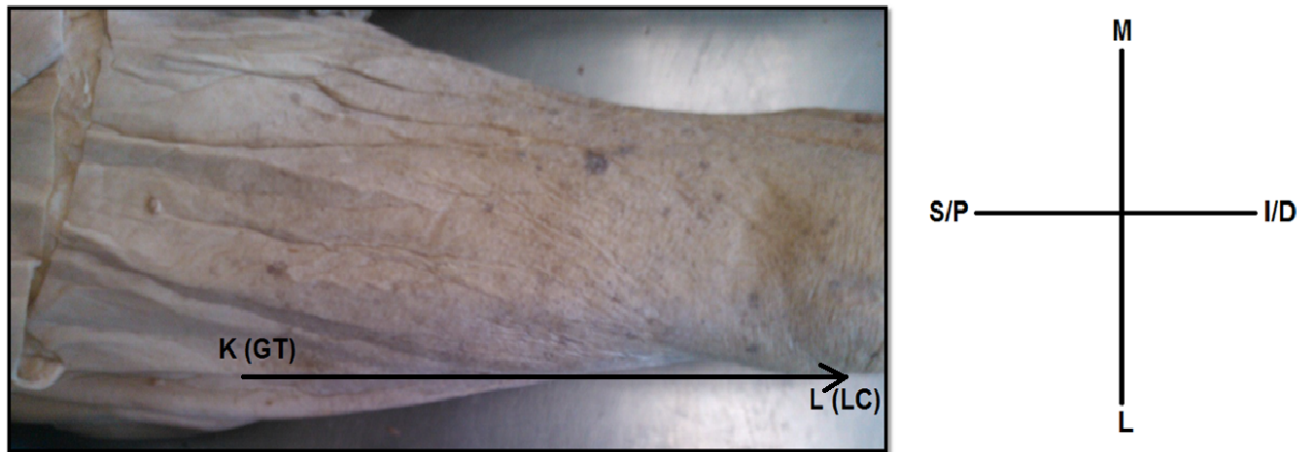


Figure 4.6: Anterior view of the thigh showing the cadaver in a supine position. The landmarks indicated are greater trochanter (K) and the most lateral aspect of the patella (L). *Key: I-Inferior; D-Distal; M-Medial; L-Lateral; S/P-Superior, Proximal; A-Anterior; P-Posterior.*

The following distances were measured (Figures 4.6, 4.7 and 4.8):

- Distance from ASIS (J) to the joint capsule (N).
- Distance from the greater trochanter (K) to the superior gluteal vessels (M).
- Distance from the greater trochanter (K) to the joint capsule (N).
- The shortest distance from the superior gluteal vessels (M) to the joint capsule (N).

A simulation of the anterolateral approach was also performed by the orthopaedic surgeon (Figure 4.5).



Figure 4.7: Anterior view of the thigh with the cadaver in a supine position. Coloured pins are used to indicate the following landmarks: ASIS (J) and the greater trochanter (K). *I-Inferior; D-Distal; M-Medial; L-Lateral; S/P-Superior, Proximal; A-Anterior; P-Posterior.*



Figure 4.8: Anterior view of the thigh with the cadaver in a supine position. The joint capsule (N) is indicated by the pointer. *I-Inferior; D-Distal; M-Medial; L-Lateral; S/P-Superior, Proximal; A-Anterior; P-Posterior.*

4.7.3. Orthopaedic simulation

One of the factors that account for the reluctance of orthopaedic surgeons to adopt the anterior approach to hip arthroplasty is the high learning curve for the anterior approach. The complications that may arise if the high learning curve is not overcome is the possibility of thigh numbness if the LFCN or any of its branches are cut (Ray *et al.*, 2010; Üzel *et al.*, 2011). Death could also result if the LCFA is severed (Keggi and Grey, 2005; Brown *et al.*, 2008). In the attempt to demonstrate the possible ease of performing hip arthroplasty using the anterior approach, it was necessary to request the assistance of a surgeon with the experience in both the anterior and the anterolateral approach.

The orthopaedic surgeon therefore, simulated the anterior approach surgical procedure on the cadaver by first palpating all the relevant anatomical landmarks before making the necessary incisions (Smith-Petersen, 1917; Smith-Petersen, 1949; Lovell, 2008). In this regard, 21 hips were firstly marked with pins, incisions made and the area around the incision dissected to assess “the level of damage,” if any, to the LFCN (Figures 9 and 10).

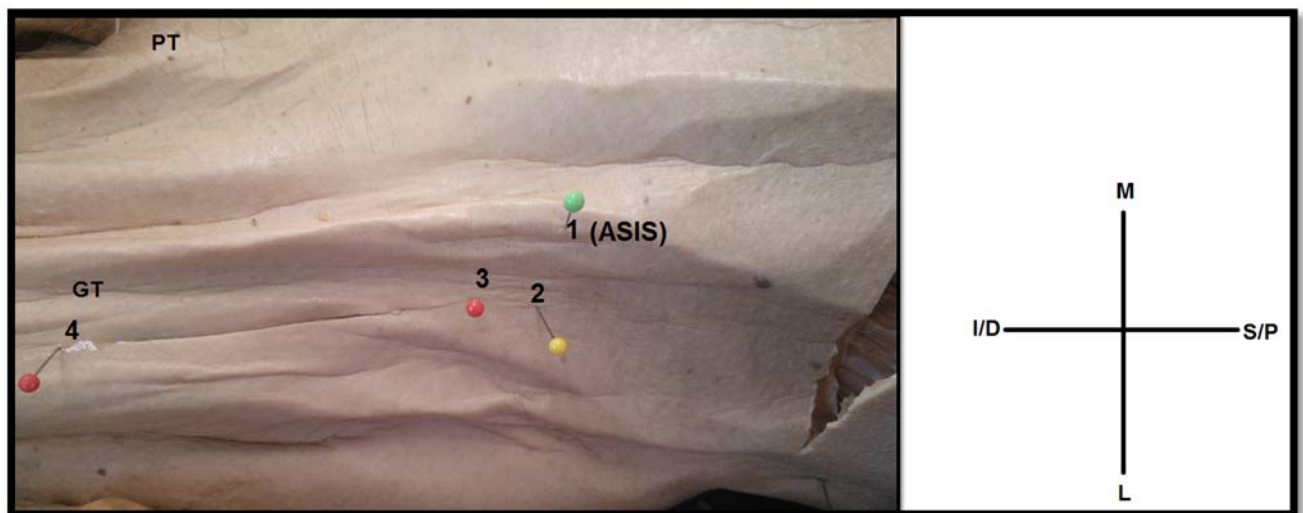


Figure 4.9: Lateral view of the thigh with the cadaver in the supine position. Pins are inserted to indicate anatomical landmarks. The first pin (1) is inserted on the ASIS, the second and third pins, 2 cm lateral (2) and inferior (3) to ASIS and the fourth (4) 2 cm medial to the greater trochanter. Key: I-Inferior; D-Distal; M-Medial; L-Lateral; S/P-Superior, Proximal; A-Anterior; P-Posterior; PT-Pubic Tubercle; GT-Greater Trochanter.

The cadavers were all in the supine position, and the following landmarks palpated: ASIS, greater trochanter of the femur and most lateral aspect of the patella. The orthopaedic surgeon's incision was then made 2 cm lateral and 2 cm inferior to the ASIS. This is important in avoiding possible damage to the LFCN which is sometimes found running on the ASIS after exiting posterior to the inguinal ligament en route to innervate the thigh. The first pin was inserted on the ASIS, the second was 2 cm lateral and inferior to ASIS, the third 2 cm medial to the greater trochanter and the fourth pin on the greater trochanter. The incision was made in the area between the second and third pins (Figure 4.9). This incision in live patients can be as small as 5 cm but is usually 8-10 cm long (Duwelius and Dorr, 2007; Sariali *et al.*, 2008; Mast and Laude, 2011; Werner and Brown, 2012). The skin around the incision was reflected medially and laterally and the LFCN, along with its branches, dissected out (Figure 4.10).

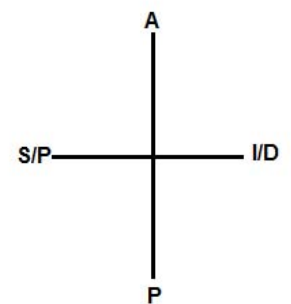
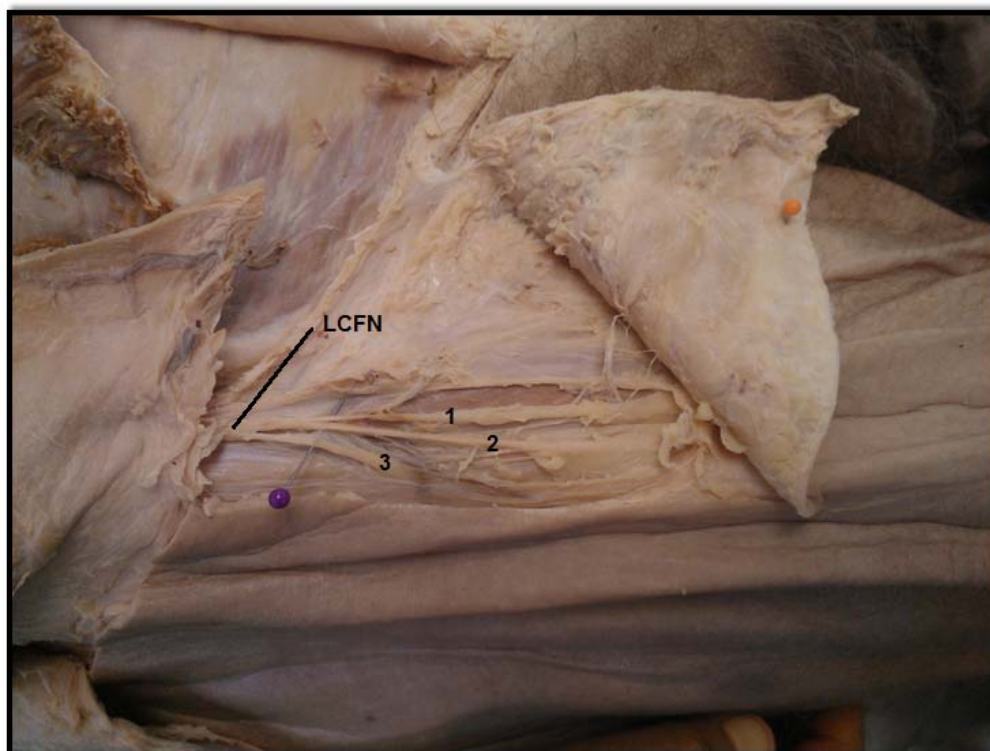


Figure 4.10: Anterolateral view of the thigh with the cadaver in the supine position. The nerve (LFCN) and all its branches (1, 2 and 3) are still intact after dissecting the area around the incision. *I-Inferior; D-Distal; M-Medial; L-Lateral; S/P-Superior, Proximal; A-Anterior; P-Posterior.*

Chapter 5

Results

5.1. Introduction

In this section the different measurements taken in relation to the LFCN, LCFA and the different anatomical landmarks (the pubic tubercle, anterior capsule of the hip joint and the ASIS) are presented. The results are presented for age, sex, height, weight and BMI as mean and standard error (SE). Comparison between groups for age, sex, height, weight and BMI are also shown. The study is a descriptive, cross-sectional, observational, quantitative study. Data was collected from cadavers to assess any possible variations in the LFCN and LCFA origin, distribution and branching patterns which might possibly have an effect on the surgical procedure during minimally invasive total hip arthroplasty when the anterior approach is used. The data analysed covers measurements taken from the anatomical landmarks to the LFCN, LCFA and other soft tissue. This section of work also documents the finding on the variations of the LCFA and the LFCN as seen in this study, further discussions of these findings is provided in chapter 6.

5.2. Sample composition

The sample for this study comprised of a total of 90 hips. Measurements captured for each variable are separated into measurements taken from the left and right hips (Table 5.1 – 5.16). The total number of cadavers is different in each table as some of the data such as height, weight and BMI were not available for some cadavers and could therefore not be captured and the data included in the results. Measurements such as the distance from where the ascending/descending branch of LCFA branches into the transverse branch (captured as ASC – TRNS) were not always available. The branching of the LCFAs ascending/descending branch into a transverse branch is an anatomical variation.

Table 5.3 and 5.4 show the total number of male and female cadavers present, from this data it can be seen that 82% (37/45) of the samples comprised of male cadavers and 18% (8/45) female cadavers. The measurements for age, height, weight and BMI are however variable, due to the unavailability of the stipulated data relating to some cadavers. In some the cadavers used for the data collection phase of the study, measurements for height, weight and BMI had not been captured prior to embalming.

5.3. Descriptive statistics for the anterior and the anterolateral approach

An analysis of variance (ANOVA) provided descriptive statistics including means, standard error (SE) and 95% confidence interval (with upper & lower limits) in the following areas; both sex groups, different age groups, height, weight and BMI (see tables 5.1 – 5.16) for the anterior and the anterolateral approach (see tables 5.17 and 5.18) to minimally invasive total hip arthroplasty.

The measurements taken on the head of the rectus femoris were analysed but the findings are not documented. The data were not documented to reasons relating to the nature of cadaver tissue. The following reasons resulted in these measurements being excluded:

1. The breadth of the rectus femoris muscle measurement is unreliable and varies due to the fixed nature of cadaver material. The measurements documented will not reflect the true breadth of this muscle as it found in a pliable state. The observation made relating to the breadth of the rectus femoris muscle, was evidence that this breadth was dependent on the position of the cadaver prior to rigor mortis (Dalal, 2006).
2. The position of the thigh in different cadavers, appeared to vary from the anatomical position displaying a slight lateral tilt. The thickness of the straight head of the rectus femoris muscle was measured at the proximal attachment, on the anterior inferior iliac spine.

5.4. Comparison per age category

In the groups where age was compared for individuals 50 years and younger and those older than 50 years, only two measurements were found to be statistically significant on the left side and none on the right side. These two measurements were the mean distances from the pubic tubercle to the LCFA and the mean distance from the pubic tubercle to the straight head of the rectus femoris muscle, respectively (table 5.1).

The measurements were analysed using *t*-test due to the comparison being only among two variables, this comparison was for the age range of individuals 50 years and younger and those older than 50 years.

5.4.1. Mean distance from the pubic tubercle to the LCFA

In the sample of individuals in the age group of 50 years and younger and those older than 50 years, significant differences were detected for measurements on the left side, the said measurements included the mean distance from the pubic tubercle to the LCFA. The statistically significant measurements ($P=0.005$) were noted to have an upper limit of 68.7 mm

for the group of individuals who were 50 years and younger, and 74.1 mm for the group older than 50 years. The lower limits were documented at 53.6 mm for the group 50 years and younger and 67.7 mm for the group older than 50 years (Table 5.1). The LCFA was measured at the branching of the profunda femoris artery or the femoral artery resulting in the LCFA branch.

5.4.2. Mean distance from the pubic tubercle to the straight head of the rectus femoris muscle (A-K)

In Table 5.1, significant differences for the distance from the pubic tubercle to the straight head of rectus femoris muscle were detected on the left side measurements. The difference was statistically significant for the p-value using the ANOVA ($P=0.045$). The upper limits for the group <50 years was documented at 84.5 mm and 87.6 mm for the group >50 years. The lower limits were captured as 70.1 mm for the group <50 years and 80.8 mm for the group >50 years.

5.5. Comparison of male and female cadaver measurements

In the data analysed for the groups comparing measurements taken from male and female samples, significant distances were detected on both the left side and the right side (table 5.3 and 5.4). The measurements were for the mean distance from the pubic tubercle to the anterior capsule of the hip joint and the mean distance from the pubic tubercle to the straight head of the rectus femoris muscle.

5.5.1. Mean distance from the pubic tubercle to the anterior capsule of the hip joint

Statistical analysis using *t*-test revealed the p-value to be $P=0.04$ (table 5.3). The statistically significant measurements are for the mean distance from the pubic tubercle to the anterior capsule of the hip joint. The mean distance indicated in this section was for the measurements on the left side. The upper limits for the males in the study was documented at 90.4 mm and 83.5 mm for the females. The lower limits were noted as 83.5 mm and 66.2 mm for the males and females, respectively.

5.5.2. Mean distance from the pubic tubercle to the straight head of rectus femoris muscle

The measurements identified to be statistically significant on the right side, were measurements from the pubic tubercle to the straight head of the rectus femoris muscle. The *t*-test revealed these measurement obtained to be $P=0.019$ (table 5.4). This difference in measurement between

males and females revealed the upper limits to be 88.9 mm for males and 81.4 mm for females. The lower limits were documented at 82.3 mm for males and 73.4 mm for females.

5.5.3. Mean distance from the ascending/descending branch of the LCFA to the branching of the transverse branch

In table 5.4, the student *t*-test revealed a significant *p*-value ($P = 0.039$) for the distance from the area where the ascending/descending branch of the LCFA first branches off the LCFA to where the ascending/descending branch branches. The branching of the ascending/descending branch of the LCFA results in the ascending/descending and transverse branches of LCFA. The *p*-value for this measurement on the right side between males and females was significant (*t*-test, $P = 0.039$). The upper limits for males were documented at 18.4 mm and 11.4 mm for females. The lower limits were 11.5 mm and 5.8 mm for males and females, respectively.

5.6. Comparison of weight ranges

Statistical significance was discovered between groups in terms of weight ranges. Weight ranges were compared for the sample of individuals with weight below 50 kg, higher and including 50 kg but less than 100 kg and more and including 100 kg. The significance for the weight ranges was detected in the right side measurements for the mean distance from the ascending/descending branch of the LCFA to where the ascending/descending branch is resulting in the ascending/descending and transverse branches of LCFA (table 5.10).

The right side measurements in table 5.10 revealed significant differences of $P = 0.017$ for the distances from the LCFA's ascending/descending branch to where the ascending/descending branch of the LCFA branches into the ascending/descending and resultant transverse branch. The mean distance refers to comparisons among individuals of varying weight ranges, in this instance no significant differences were detected on the left side. The upper and lower limits for the weight ranges below 50 kg was 19.5 mm and 7.7 mm, respectively. The upper limits for the group of the weight range from 50 kg but less than 100 kg was 17.4 mm, with the lower limit of 9.8 mm. The last group of weight ranges higher than 100 kg showed the upper limits to be 36.0 mm with the lower limits documented at 0.1 mm.

5.7. Comparison of individuals in various BMI ranges

Four categories of BMI were created, less than 18 kg/m², 18 kg/m² to 25 kg/m², 25.1 kg/m² to 30 kg/m² and lastly, higher than 30 kg/m². The measurements were analysed using ANOVA,

post hoc comparisons with Bonferroni correction and LSD in order to eliminate the possibility of type 1 error (Royall, 1986). Type 1 error normally occurs when a significance test results in the rejection of a true null hypothesis (Royall, 1986). The p-values of ANOVA comparison with LSD revealed significant differences in the left side measurements, for the mean distance from the anterior capsule of the hip joint to the branching of LCFA from the profunda femoris artery or femoral artery (table 5.14).

The analysis of the p-values for ANOVA comparison with LSD were significant ($P=0.046$) when comparing the distance in individuals with a BMI between 18-25 kg/m² and those with a BMI between 25.1-30 kg/m², respectively. The p-value indicated is for the distance from the anterior capsule of the hip joint to the distance where the LCFA branches from the profunda femoris artery or the directly off the femoral artery into the ascending, descending and transverse branches (table 5.14).

5.8. Average distances from the anatomical landmarks in relation to the LFCN, LCFA and the branches of the LCFA

This section of the study documents findings made relating to the pubic tubercle, ASIS, LFCN, LCFA and the branches of the LCFA. The measurements captured in this section were not proven to be statistically significant, however, it is important that they are documented in order to relate the findings made in this study to current literature. Further discussion of these results, will be included in chapter 6 where they will be related to the documented significant findings.

5.8.1. The average distance from the femoral artery to the profunda femoris artery

The average distance for the majority 88 of the 90 (97.8%) hips dissected, showed the distance from the femoral artery (where it is seen distal to the inguinal ligament) to the branching of the profunda femoris artery to be 38.9 mm. In 2.2% (2/90) of the hips dissected, the profunda femoris artery posterior to the inguinal ligament. The distance for the left side measurements was documented to be 36.8 mm for 49% (44/90) hips dissected and 44 mm for the right side measurements of 49% (44/90) hips. The highest measurement for the left side was 64 mm with the lowest measurement being 9 mm. The highest measurement for the right side measurement was documented at 71 mm with the lowest being 10 mm.

5.8.2. The average distance from the ASIS to the LFCN

The average distance for the left and right hips dissected was captured as 13.6 mm for 44 % (40/90) of the hips dissected on the left and 12.6 mm for 50% (45/90) of the hips dissected on

the right. In 6% (5/90) of the hips dissected the nerve coursed directly over the ASIS. The highest measurement for the left side was 39 mm with the lowest measurement being 0 mm. The highest measurement for the right side measurement was documented at 49 mm with the lowest being 0 mm.

5.8.3. Average distance from the LCFA to the branching into the respective branches

The measurement taken from the LCFA to the branching of the LCFA into the ascending, descending and transverse branches were 1.6 cm for both the left and right side measurements. On the left side, data was collected from 44.4% (40/90) of the hips dissected and 43.3% (39/90) of the hips on the right. In the remaining 12.2% (11/90) of the dissected hips, the branching of the LCFA into its varying branches was immediate. The study noted that when looking at the branching pattern of the LCFA in the study sample, the LCFA seemed to branch into the three branches (ascending, descending and transverse) a short distance from the initial branching from the profunda femoris artery or the femoral artery. This branching pattern was noted in 87.8% (79/90) of the dissected hips with 12.2% (11/90) of the dissected hips showing the LCFA branching immediately after its branching from the profunda femoris artery or the femoral artery.

5.8.4. Average distance from the profunda femoris artery to the branching of the LCFA

This measurement were in cadavers where the LCFA branched from the profunda femoris artery. The consistency was noted in 43% (34/90) of the hips for the left side measurements and 41% (37/90) of the hips for the right side measurements. The average distance from the profunda femoris artery branching from the femoral artery to where the LCFA branches from the profunda femoris artery or the femoral artery was documented as 17.9 mm on the left side and 17.3 mm on the right side. The highest measurement for the left side was 51 mm with the lowest measurement being 0 mm. The highest measurement for the right side measurement was documented at 40 mm with the lowest being 0 mm.

5.8.5. Average distance from the pubic tubercle to the ASIS

The measurements analysed are for the distance of the two anatomical landmarks, the pubic tubercle and the ASIS. The distance averaged for the anatomical landmarks is 106.7 mm on the left side for 50% (45/90) hips dissected and the 107.2 mm on the right side for 50% (45/90) hips dissected. The highest measurement for the left side was 143 mm with the lowest

measurement being 77 mm. The highest measurement for the right side measurement was documented at 144 mm with the lowest being 64 mm.

5.8.6. Average distance from the ascending/descending branch of LCFA branching resulting in the ascending/descending and the transverse branches

The data captured refers to the distance of a branch of the LCFA, either the ascending or descending branch. In some instances, the ascending/descending branch of the LCFA bifurcates resulting in the ascending/descending branch and the transverse branch of LCFA. The distance on the left side is captured as 10.1 mm in 42% (38/90) of the hips dissected and 13.3 mm on the right side in 36% (32/90) hips dissected. The highest measurement for the left side was 20 mm with the lowest measurement being 3 mm. The highest measurement for the right side measurement was documented at 36 mm with the lowest being 4 mm.

Table 5.1. Left side measurements in a sample of ages <50 years and >50 years

Landmark	Group	N	Mean	SE	95% Confidence Interval		t-test, p-value	Difference in mm (<50 minus >50)
A - F	<50	13	81.2308	4.04328	72.4212	90.0403	0.139	-5.48
	>50	31	86.7097	1.64885	83.3423	90.0771		
	Total	44	85.0909	1.68215	81.6985	88.4833		
A – G	<50	13	103.7692	4.10621	94.8226	112.7159	0.336	-4.62
	>50	31	108.3871	2.54283	103.1939	113.5802		
	Total	44	107.0227	2.16143	102.6638	111.3817		
A – I	<50	13	61.1538	3.44898	53.6392	68.6685	0.005	-9.75
	>50	31	70.9032	1.55291	67.7318	74.0747		
	Total	44	68.0227	1.62059	64.7545	71.2910		
A – K	<50	13	77.3077	3.30769	70.1008	84.5145	0.045	-6.89
	>50	31	84.1935	1.65680	80.8099	87.5772		
	Total	44	82.1591	1.57509	78.9826	85.3356		
D – G	<50	10	12.4000	2.91433	5.8073	18.9927	0.610	-1.67
	>50	30	14.0667	1.59808	10.7982	17.3351		
	Total	40	13.6500	1.38839	10.8417	16.4583		
F – G	<50	13	62.9231	2.34647	57.8106	68.0356	0.241	5.50
	>50	31	57.4194	2.81424	51.6719	63.1668		
	Total	44	59.0455	2.11981	54.7704	63.3205		
F – I	<50	13	40.3846	3.43724	32.8955	47.8737	0.207	-5.23
	>50	31	45.6129	2.21611	41.0870	50.1388		
	Total	44	44.0682	1.87630	40.2843	47.8521		
ASC – TRNS	<50	11	8.5455	1.33051	5.5809	11.5100	0.175	-2.29
	>50	25	10.8400	0.93038	8.9198	12.7602		
	Total	36	10.1389	0.77373	8.5681	11.7096		
F – I ₃	<50	13	46.9231	3.14084	40.0798	53.7664	0.761	1.28
	>50	28	45.6429	2.44528	40.6256	50.6602		
	Total	41	46.0488	1.92447	42.1593	49.9383		
DAT – I	<50	7	10.2857	2.69668	3.6872	16.8843	0.078	-9.71
	>50	26	20.0000	2.64633	14.5498	25.4502		
	Total	33	17.9394	2.25670	13.3426	22.5361		
FA – DAT	<50	13	39.7692	4.28796	30.4266	49.1119	0.374	4.20
	>50	30	35.5667	2.46245	30.5304	40.6029		
	Total	43	36.8372	2.14428	32.5099	41.1645		
I – BIFR	<50	13	19.3077	2.05808	14.8235	23.7919	0.107	4.73
	>50	26	14.5769	1.74371	10.9857	18.1682		
	Total	39	16.1538	1.38214	13.3559	18.9518		

Significant differences between groups are highlighted (t-test, $p \leq 0.05$)

Table 5.2. Right side measurements in a sample of ages <50 years and >50 years

Landmark	Group	N	Mean	SE	95% Confidence Interval		t-test, p-value	Difference in mm (<50 minus >50)
A - F	<50	13	88.5385	2.72363	82.6042	94.4727	0.867	-0.59
	>50	30	89.1333	1.99640	85.0502	93.2164		
	Total	43	88.9535	1.60079	85.7230	92.1840		
A – G	<50	13	102.6923	3.38432	95.3185	110.0661	0.202	-6.67
	>50	30	109.3667	3.04392	103.1411	115.5922		
	Total	43	107.3488	2.38254	102.5407	112.1570		
A – I	<50	13	69.3077	3.49062	61.7023	76.9131	0.512	-2.79
	>50	30	72.1000	2.32693	67.3409	76.8591		
	Total	43	71.2558	1.92354	67.3740	75.1377		
A – K	<50	13	82.0000	2.17208	77.2674	86.7326	0.289	-3.30
	>50	30	85.3000	1.78316	81.6530	88.9470		
	Total	43	84.3023	1.41207	81.4526	87.1520		
D – G	<50	13	13.5385	3.03318	6.9297	20.1472	0.697	1.34
	>50	30	12.2000	1.82032	8.4770	15.9230		
	Total	43	12.6047	1.54917	9.4783	15.7310		
F – G	<50	13	61.5385	2.98633	55.0318	68.0451	0.995	-0.03
	>50	30	61.5667	2.60886	56.2309	66.9024		
	Total	43	61.5581	2.01223	57.4973	65.6190		
F – I	<50	13	46.6154	3.83563	38.2583	54.9725	0.955	0.25
	>50	30	46.3667	2.32897	41.6034	51.1299		
	Total	43	46.4419	1.97080	42.4646	50.4191		
ASC – TRNS	<50	12	12.0833	2.00174	7.6775	16.4891	0.415	-2.36
	>50	18	14.4444	1.90497	10.4253	18.4636		
	Total	30	13.5000	1.38941	10.6583	16.3417		
F – I ₃	<50	13	49.7692	3.28000	42.6227	56.9157	0.633	1.92
	>50	27	47.8519	2.27065	43.1845	52.5192		
	Total	40	48.4750	1.84842	44.7362	52.2138		
DAT – I	<50	11	20.0000	3.45359	12.3049	27.6951	0.419	3.04
	>50	24	16.9583	1.96295	12.8977	21.0190		
	Total	35	17.9143	1.71713	14.4247	21.4039		
FA – DAT	<50	13	41.6923	3.55070	33.9560	49.4286	0.865	0.76
	>50	29	40.9310	2.51348	35.7824	46.0797		
	Total	42	41.1667	2.03081	37.0654	45.2680		
I – BIFR	<50	13	14.8462	2.25561	9.9316	19.7607	0.450	-2.74
	>50	24	17.5833	2.32731	12.7689	22.3977		
	Total	37	16.6216	1.69939	13.1751	20.0681		

Significant differences between groups are highlighted (t-test, $p \leq 0.05$)

Table 5.3. Left side measurements in a sample comparing gender (males and females)

Landmark	Group	N	Mean	SE	95% Confidence Interval		t-test, p-value	Difference in mm (Males minus Females)
A - F	Males	37	86.9459	1.69212	83.5142	90.3777	0.04	12.07
	Females	8	74.8750	3.65688	66.2279	83.5221		
	Total	45	84.8000	1.66988	81.4346	88.1654		
A – G	Males	37	107.5676	2.48072	102.5364	112.5987	0.372	5.07
	Females	8	102.5000	3.59563	93.9977	111.0023		
	Total	45	106.6667	2.14264	102.3485	110.9849		
A – I	Males	37	68.1892	1.86795	64.4008	71.9776	0.607	2.19
	Females	8	66.0000	2.63222	59.7758	72.2242		
	Total	45	67.8000	1.59975	64.5759	71.0241		
A – K	Males	37	83.9189	1.58227	80.7099	87.1279	0.06	10.92
	Females	8	73.0000	3.38062	65.0061	80.9939		
	Total	45	81.9778	1.55033	78.08533	85.1023		
D – G	Males	34	13.3529	1.55579	10.1877	16.5182	0.653	-1.65
	Females	7	15.0000	2.56348	8.7274	21.2726		
	Total	41	13.6341	1.35420	10.8972	16.3711		
F – G	Males	37	59.7297	2.37405	54.9149	64.5445	0.366	4.98
	Females	8	54.7500	4.03445	45.2100	64.2900		
	Total	45	58.8444	2.08190	54.6487	63.0402		
F – I	Males	37	44.2973	2.09349	40.0515	48.5431	0.790	1.30
	Females	8	43.0000	3.80789	33.9958	52.0042		
	Total	45	44.0667	1.83413	40.3702	47.7631		
ASC – TRNS	Males	32	9.9375	0.88210	8.1384	11.7366	0.909	-0.26
	Females	5	10.2000	0.96954	7.5081	12.8919		
	Total	37	9.9730	0.77060	8.4101	11.5358		
F – I ₃	Males	36	46.2500	2.10229	41.9821	50.5179	0.726	1.92
	Females	6	44.3333	4.06339	33.8881	54.7786		
	Total	42	45.9762	1.87950	42.1805	49.7719		
DAT – I	Males	26	16.3077	2.34210	11.4840	21.1313	0.191	-6.82
	Females	8	23.1250	5.22507	10.7697	35.4803		
	Total	34	17.9118	2.18949	13.4572	22.3663		
FA – DAT	Males	37	37.7027	2.20696	33.2268	42.1786	0.325	5.70
	Females	7	32.0000	6.22591	16.7658	47.2342		
	Total	44	36.7955	2.09539	32.5697	41.0212		
I – BIFR	Males	34	16.8235	1.54058	13.6892	19.9579	0.151	5.49
	Females	6	11.3333	1.30809	7.9708	14.6959		
	Total	40	16.0000	1.35590	13.2574	18.7426		

Significant differences between groups are highlighted (t-test, $p \leq 0.05$)

Table 5.4. Right side measurements in a sample comparing gender (males and females)

Landmark	Group	N	Mean	SE	95% Confidence Interval		t-test, p-value	Difference in mm (Males minus Females)
A – F	Males	35	90.6571	1.78177	87.0362	94.2781	0.09	10.21
	Females	9	80.4444	2.31007	75.1174	85.7715		
	Total	44	88.5682	1.61075	85.3198	91.8166		
A – G	Males	35	109.0000	2.77110	103.3684	114.6316	0.131	8.78
	Females	9	100.2222	2.89049	93.5567	106.8877		
	Total	44	107.2045	2.33223	102.5012	111.9079		
A – I	Males	35	75.6857	2.25059	68.1120	77.2595	0.53	12.24
	Females	9	63.4444	2.48390	57.7166	69.1723		
	Total	44	70.7955	1.93488	66.8934	74.6975		
A – K	Males	35	85.6000	1.63172	82.2839	88.9161	0.019	8.16
	Females	9	77.4444	1.73294	73.4483	81.4406		
	Total	44	83.9318	1.42849	81.0510	86.8126		
D – G	Males	35	11.4857	1.49080	8.4561	14.5154	0.152	-5.40
	Females	9	16.8889	4.53518	6.4307	27.3470		
	Total	44	12.5909	1.51362	9.5384	15.6434		
F – G	Males	35	63.1714	2.28016	58.5376	67.8053	0.119	7.62
	Females	9	55.5556	3.15397	48.2825	62.8286		
	Total	44	61.6136	1.96675	57.6473	65.5800		
F – I	Males	35	47.6000	2.27489	42.9769	52.2231	0.158	6.82
	Females	9	40.7778	2.95700	33.9589	47.5966		
	Total	44	46.2045	1.94006	42.2920	50.1170		
ASC – TRNS	Males	23	14.9565	1.65918	11.5156	18.3975	0.039	6.33
	Females	8	8.6250	1.17925	5.8365	11.4135		
	Total	31	13.3226	1.35550	10.5543	16.0909		
F – I ₃	Males	32	49.3125	2.16340	44.9002	53.7248	0.273	4.87
	Females	9	44.4444	2.90646	37.7421	51.1468		
	Total	41	48.2439	1.81752	44.5706	51.9173		
DAT – I	Males	28	17.6429	1.90947	13.7250	21.5608	0.902	0.52
	Females	8	17.1250	4.09458	7.4428	26.8072		
	Total	36	17.5278	1.71292	14.0504	21.0052		
FA – DAT	Males	34	42.4118	2.51906	38.0191	46.8044	0.200	6.30
	Females	9	36.1111	4.71241	25.2443	46.9779		
	Total	43	41.0930	1.98438	37.0884	45.0977		
I – BIFR	Males	29	16.2759	2.08614	12.0026	20.5491	0.747	-1.28
	Females	9	17.5556	2.05556	12.8154	22.2957		
	Total	38	16.5789	1.65461	13.2264	19.9315		

Significant differences between groups are highlighted (t-test, $p \leq 0.05$)

Table 5.5. Left side measurements comparing height differences in the sample for individuals <1.6 m and >1.6 m

Landmark	Group	N	Mean	SE	95% Confidence Interval		t-test, p-value	Difference in mm (<1.6 m minus >1.6 m)
A – F	<1.6	3	78.0000	0.57735	75.5159	80.4841	0.116	-10.85
	>1.6	27	88.8519	2.19213	84.3459	93.3578		
	Total	30	87.7667	2.06040	83.5527	91.9807		
A – G	<1.6	3	105.0000	5.29150	82.2325	127.7675	0.580	-5.48
	>1.6	27	110.4815	3.17772	103.9496	117.0134		
	Total	30	109.9333	2.90419	103.9936	115.8731		
A – I	<1.6	3	59.6667	4.09607	42.0427	77.2906	0.72	-12.00
	>1.6	27	71.6667	2.07412	67.4032	75.9301		
	Total	30	70.4667	2.00845	66.3589	74.5744		
A – K	<1.6	3	74.6667	1.76383	67.0775	82.2558	0.090	-11.04
	>1.6	27	85.7037	2.05329	81.4831	89.9243		
	Total	30	84.6000	1.94971	80.6124	88.5876		
D – G	<1.6	3	9.0000	2.08167	0.0433	17.9567	0.230	-7.08
	>1.6	26	16.0769	1.91747	12.1278	20.0260		
	Total	29	15.3448	1.77231	11.7144	18.9752		
F – G	<1.6	3	57.6667	5.36449	34.5851	80.7482	0.937	-0.78
	>1.6	27	58.4444	3.13892	51.9923	64.8966		
	Total	30	58.3667	2.85491	52.5277	64.2056		
F – I	<1.6	3	38.3333	4.40959	19.3604	57.3062	0.217	-9.59
	>1.6	27	47.9259	2.45931	42.8707	52.9811		
	Total	30	46.9667	2.30216	42.2582	51.6751		
ASC – TRNS	<1.6	3	9.3333	1.45297	3.0817	15.5849	0.599	-1.62
	>1.6	23	10.9565	1.06782	8.7420	13.1710		
	Total	26	10.7692	0.95806	8.7961	12.7424		
F – I ₃	<1.6	3	43.3333	3.17980	29.6518	57.0149	0.559	-4.79
	>1.6	24	48.1250	2.79058	42.3522	53.8978		
	Total	27	47.5926	2.50939	42.4345	52.7507		
DAT – I	<1.6	2	34.5000	16.50000	-175.1524	244.1524	0.121	16.05
	>1.6	22	18.4545	2.73563	12.7655	24.1436		
	Total	24	19.7917	2.84693	13.9023	25.6810		
FA – DAT	<1.6	2	31.5000	13.50000	-140.0338	203.0338	0.547	-6.87
	>1.6	27	38.3704	2.92933	32.3478	44.3929		
	Total	29	37.8966	2.82466	32.1105	43.6826		
I – BIFR	<1.6	3	16.3333	4.33333	-2.3115	34.9782	0.926	0.56
	>1.6	22	15.7727	2.10640	11.3922	20.1532		
	Total	25	15.8400	1.89884	11.9210	19.7590		

Significant differences between groups are highlighted (*t*-test, $p \leq 0.05$)

Table 5.6. Right side measurements comparing height differences in the sample for individuals <1.6 m and >1.6 m

Landmark	Group	N	Mean	SE	95% Confidence Interval		t-test, p-value	Difference in mm (<1.6 m minus >1.6 m)
A - F	<1.6	5	81.2000	3.95474	70.2199	92.1801	0.073	-10.06
	>1.6	27	91.2593	2.20178	86.7334	95.7851		
	Total	32	89.6875	2.04360	85.5196	93.8554		
A – G	<1.6	5	97.0000	3.92428	86.1044	107.8956	0.079	-14.07
	>1.6	27	111.0741	3.21939	104.4565	117.6916		
	Total	32	108.8750	2.91331	102.9333	114.8167		
A – I	<1.6	5	61.8000	3.70675	51.5084	72.0916	0.070	-10.68
	>1.6	27	72.4815	2.32928	67.6936	77.2694		
	Total	32	70.8125	2.14515	66.4374	75.1876		
A – K	<1.6	5	77.8000	2.59615	70.5919	85.0081	0.058	-8.98
	>1.6	27	86.7778	1.88511	82.9029	90.6527		
	Total	32	85.3750	1.73016	81.8463	88.9037		
D – G	<1.6	5	19.2000	8.25470	-3.7187	42.1187	0.250	6.35
	>1.6	27	12.8519	1.82707	9.0963	16.6074		
	Total	32	13.8438	1.97673	9.8122	17.8753		
F – G	<1.6	5	52.6000	4.92544	38.9248	66.2752	0.142	-9.33
	>1.6	27	61.9259	2.48982	56.8080	67.0438		
	Total	32	60.4688	2.29040	55.7974	65.1401		
F – I	<1.6	5	37.4000	5.49181	22.1523	52.6477	0.058	-12.67
	>1.6	27	50.0741	2.56590	44.7998	55.3484		
	Total	32	48.0938	2.43933	43.1187	53.0688		
ASC – TRNS	<1.6	5	11.4000	3.26497	2.3350	20.4650	0.332	-4.04
	>1.6	18	15.4444	1.93897	11.3536	19.5353		
	Total	23	14.5652	1.67972	11.0817	18.0487		
F – I ₃	<1.6	5	40.8000	4.48776	28.3400	53.2600	0.082	-10.74
	>1.6	26	51.5385	2.45653	46.4791	56.5978		
	Total	31	49.8065	2.27394	45.1625	54.4505		
DAT – I	<1.6	3	12.6667	1.76383	5.0775	20.2558	0.587	-3.38
	>1.6	23	16.0435	2.17012	11.5429	20.5440		
	Total	26	15.6538	1.93426	11.6702	19.6375		
FA – DAT	<1.6	5	35.8000	6.46065	17.8624	53.7376	0.231	-8.08
	>1.6	26	43.8846	2.62668	38.4749	49.2944		
	Total	31	42.5806	2.45246	37.5721	47.5892		
I – BIFR	<1.6	5	17.6000	3.34066	8.3248	26.8752	0.744	1.78
	>1.6	22	15.8182	2.43499	10.7543	20.8820		
	Total	27	16.1481	2.05875	11.9163	20.3800		

Significant differences between groups are highlighted (*t*-test, $p \leq 0.05$)

Table 5.7: Left side measurements comparing individuals of different weight ranges using ANOVA

Landmark	Group	N	Mean	SE	95% Confidence Interval		ANOVA, p-value
A - F	<50	10	85.0000	3.63929	76.7674	93.2326	0.412
	<100	18	88.3333	2.63337	82.7774	93.8893	
	>100	2	96.5000	8.50000	-11.5027	204.5027	
	Total	30	87.7667	2.06040	83.5527	91.9807	
A – G	<50	10	103.8000	3.38231	96.1487	111.4513	0.310
	<100	18	112.5000	4.27277	103.4853	121.5147	
	>100	2	117.5000	7.50000	22.2035	212.7965	
	Total	30	109.9333	2.90419	103.9936	115.8731	
A – I	<50	10	68.9000	4.03719	59.7672	78.0328	0.682
	<100	18	70.6667	2.51271	65.3653	75.9680	
	>100	2	76.5000	2.50000	44.7345	108.2655	
	Total	30	70.4667	2.00845	66.3589	74.5744	
A – K	<50	10	82.4000	2.83314	75.9910	88.8090	0.740
	<100	18	85.6667	2.84685	79.6603	91.6730	
	>100	2	86.0000	4.00000	35.1752	136.8248	
	Total	30	84.6000	1.94971	80.6124	88.5876	
D – G	<50	10	15.9000	2.94184	9.2451	22.5549	0.976
	<100	17	15.0588	2.52556	9.7049	20.4128	
	>100	2	15.0000	4.00000	-35.8248	65.8248	
	Total	29	15.3448	1.77231	11.7144	18.9752	
F – G	<50	10	55.4000	3.25303	48.0411	62.7589	0.472
	<100	18	58.6667	4.00735	50.2119	67.1214	
	>100	2	70.5000	20.50000	-189.9772	330.9772	
	Total	30	58.3667	2.85491	52.5277	64.2056	
F – I	<50	10	48.5000	3.11002	41.4646	55.5354	0.544
	<100	18	47.1667	3.34532	40.1087	54.2247	
	>100	2	37.5000	7.50000	-57.7965	132.7965	
	Total	30	46.9667	2.30216	42.2582	51.6751	
ASC – TRNS	<50	9	10.4444	1.60823	6.7358	14.1530	0.747
	<100	15	11.2667	1.37136	8.3254	14.2079	
	>100	2	8.5000	0.50000	2.1469	14.8531	
	Total	26	10.7692	0.95806	8.7961	12.7424	
F – I ₃	<50	8	47.0000	2.48567	41.1223	52.8777	0.474
	<100	17	49.1176	3.59726	41.4918	56.7435	
	>100	2	37.0000	12.00000	-115.4745	189.4745	
	Total	27	47.5926	2.50939	42.4345	52.7507	
DAT – I	<50	8	15.7500	2.29713	10.3182	21.1818	0.624
	<100	14	21.8571	4.09886	13.0021	30.7122	
	>100	2	21.5000	21.50000	-251.6834	294.6834	
	Total	24	19.7917	2.84693	13.9023	25.6810	

Significant differences between groups are highlighted (ANOVA, $p \leq 0.05$)

Table 5.7: Left side measurements comparing individuals of different weight ranges using ANOVA

Landmark	Group	N	Mean	SE	95% Confidence Interval		ANOVA, p-value
FA – DAT	<50	10	41.9000	4.79919	31.0435	52.7565	0.456
	<100	17	36.7059	3.48501	29.3180	44.0938	
	>100	2	28.0000	19.00000	-213.4179	269.4179	
	Total	29	37.8966	2.82466	32.1105	43.6826	
I – BIFR	<50	7	10.5714	2.53412	4.3707	16.7722	0.230
	<100	16	17.8125	2.58073	12.3118	23.3132	
	>100	2	18.5000	3.50000	-25.9717	62.9717	
	Total	25	15.8400	1.89884	11.9210	19.7590	

Significant differences between groups are highlighted (ANOVA, $p \leq 0.05$)

Table 5.8: Left side measurements for p-values of ANOVA comparisons with Bonferroni correction in the different weight ranges

Landmark	Group			
		<50	<100	>100
A - F	<50	X	1.000	0.602
	<100	1.000	X	1.000
	>100	0.602	1.000	X
A – G	<50	X	0.521	0.817
	<100	0.521	X	1.000
	>100	0.817	1.000	X
A – I	<50	X	1.000	1.000
	<100	1.000	X	1.000
	>100	1.000	1.000	X
A – K	<50	X	1.000	1.000
	<100	1.000	X	1.000
	>100	1.000	1.000	X
D – G	<50	X	1.000	1.000
	<100	1.000	X	1.000
	>100	1.000	1.000	X
F – G	<50	X	1.000	0.680
	<100	1.000	X	0.968
	>100	0.680	0.968	X
F – I	<50	X	1.000	0.828
	<100	1.000	X	0.957
	>100	0.828	0.957	X
ASC – TRNS	<50	X	1.000	1.000
	<100	1.000	X	1.000
	>100	1.000	1.000	X
F – I ₃	<50	X	1.000	1.000
	<100	1.000	X	0.689
	>100	1.000	0.689	X
DAT – I	<50	X	01.000	1.000
	<100	1.000	X	1.000
	>100	1.000	1.000	X
FA – DAT	<50	X	1.000	0.756
	<100	1.000	X	1.000
	>100	0.756	1.000	X
I – BIFR	<50	X	0.297	0.894
	<100	0.297	X	1.000
	>100	0.894	1.000	X

Significant differences between groups are highlighted (ANOVA, $p \leq 0.05$)

Table 5.9: Left side measurements for p-values of ANOVA comparisons with LSD in the different weight ranges

Landmark	Group			
		<50	<100	>100
A - F	<50	X	0.462	0.201
	<100	0.462	X	0.342
	>100	0.201	0.342	X
A – G	<50	X	0.174	0.272
	<100	0.174	X	0.674
	>100	0.272	0.674	X
A – I	<50	X	0.693	0.390
	<100	0.693	X	0.492
	>100	0.390	0.492	X
A – K	<50	X	0.456	0.674
	<100	0.456	X	0.968
	>100	0.674	0.968	X
D – G	<50	X	0.833	0.907
	<100	0.833	X	0.994
	>100	0.907	0.994	X
F – G	<50	X	0.604	0.227
	<100	0.604	X	0.323
	>100	0.227	0.323	X
F – I	<50	X	0.793	0.276
	<100	0.793	X	0.319
	>100	0.276	0.319	X
ASC – TRNS	<50	X	0.702	0.626
	<100	0.702	X	0.472
	>100	0.626	0.472	X
F – I ₃	<50	X	0.711	0.346
	<100	0.711	X	0.230
	>100	0.346	0.230	X
DAT – I	<50	X	0.345	0.616
	<100	0.345	X	0.974
	>100	0.616	0.974	X
FA – DAT	<50	X	0.403	0.252
	<100	0.403	X	0.454
	>100	0.252	0.454	X
I – BIFR	<50	X	0.099	0.298
	<100	0.099	X	0.922
	>100	0.298	0.922	X

Significant differences between groups are highlighted (ANOVA, $p \leq 0.05$)

Table 5.10. Right side measurements in a sample comparing individuals of different weight ranges for p-values using ANOVA

Landmark	Group	N	Mean	SE	95% Confidence Interval		ANOVA, p-value
A - F	<50	11	85.1818	3.35158	77.7140	92.6496	0.133
	<100	19	91.0526	2.59833	85.5937	96.5115	
	>100	2	101.5000	5.50000	31.6159	171.3841	
	Total	32	89.6875	2.04360	85.5196	93.8554	
A - G	<50	11	107.8182	4.36894	98.0836	117.5528	0.964
	<100	19	109.3158	4.20043	100.4910	118.1406	
	>100	2	110.5000	11.50000	-35.6214	256.6214	
	Total	32	108.8750	2.91331	102.9333	114.8167	
A - I	<50	11	67.4545	3.14314	60.4512	74.4579	0.339
	<100	19	71.7368	3.03281	65.3652	78.1085	
	>100	2	80.5000	1.50000	61.4407	99.5593	
	Total	32	70.8125	2.14515	66.4374	75.1876	
A - K	<50	11	81.7273	2.65293	75.8162	87.6384	0.234
	<100	19	86.7368	2.36426	81.7697	91.7040	
	>100	2	92.5000	0.50000	86.1469	98.8531	
	Total	32	85.3750	1.73016	81.8463	88.9037	
D - G	<50	11	13.5455	4.01670	4.5957	22.4952	0.736
	<100	19	13.3684	2.33109	8.4710	18.2659	
	>100	2	20.0000	9.00000	-94.3558	134.3558	
	Total	32	13.8438	1.97673	9.8122	17.8753	
F - G	<50	11	60.4545	3.42548	52.8221	68.0870	0.600
	<100	19	59.5263	2.86578	53.5055	65.5471	
	>100	2	69.5000	21.50000	-203.6834	342.6834	
	Total	32	60.4688	2.29040	55.7974	65.1401	
F - I	<50	11	44.5455	4.45250	34.6247	54.4663	0.562
	<100	19	50.2632	2.98225	43.9977	56.5286	
	>100	2	47.0000	15.00000	-143.5931	237.5931	
	Total	32	48.0938	2.43933	43.1187	53.0688	
ASC – TRNS	<50	9	13.5556	2.55556	7.6624	19.4487	0.017
	<100	13	13.6154	1.74877	9.8051	17.4256	
	>100	1	36.0000				
	Total	23	14.5652	1.67972	11.0817	18.0487	
F - I ₃	<50	10	47.7000	3.90456	38.8673	56.5327	0.296
	<100	19	52.1053	2.73369	46.3620	57.8485	
	>100	2	38.5000	15.50000	-158.4462	235.4462	
	Total	31	49.8065	2.27394	45.1625	54.4505	

Significant differences between groups are highlighted (ANOVA $p \leq 0.05$)

Table 5.10. Right side measurements in a sample comparing individuals of different weight ranges for p-values using ANOVA

Landmark	Group	N	Mean	SE	95% Confidence Interval		ANOVA, p-value
DAT – I	<50	9	12.0000	1.90029	7.6179	16.3821	0.349
	<100	15	18.0667	2.73159	12.2080	23.9253	
	>100	2	14.0000	14.00000	-163.8869	191.8869	
	Total	26	15.6538	1.93426	11.6702	19.6375	
FA – DAT	<50	11	43.6364	4.81338	32.9115	54.3612	0.907
	<100	18	41.6667	2.81685	35.7236	47.6097	
	>100	2	45.0000	17.00000	-171.0055	261.0055	
	Total	31	42.5806	2.45246	37.5721	47.5892	
I – BIFR	<50	7	15.0000	2.23607	9.5285	20.4715	0.916
	<100	18	16.7778	2.99406	10.4609	23.0947	
	>100	2	14.5000	0.50000	8.1469	20.8531	
	Total	27	16.1481	2.05875	11.9163	20.3800	

Significant differences between groups are highlighted (ANOVA, $p \leq 0.05$)

Table 5.11: Right side measurements for p-values of ANOVA comparisons with Bonferroni correction in the different weight ranges

Landmark	Group			
		<50	<100	>100
A - F	<50	X	0.526	0.201
	<100	0.526	X	0.653
	>100	0.201	0.653	X
A – G	<50	X	1.000	1.000
	<100	1.000	X	1.000
	>100	1.000	1.000	X
A – I	<50	X	1.000	0.513
	<100	1.000	X	1.000
	>100	0.513	1.000	X
A – K	<50	X	0.540	0.468
	<100	0.540	X	1.000
	>100	0.468	1.000	X
D – G	<50	X	1.000	1.000
	<100	1.000	X	1.000
	>100	1.000	1.000	X
F – G	<50	X	1.000	1.000
	<100	1.000	X	0.949
	>100	1.000	0.949	X
F – I	<50	X	0.868	1.000
	<100	0.868	X	1.000
	>100	1.000	1.000	X
F – I ₃	<50	X	1.000	1.000
	<100	1.000	X	0.467
	>100	1.000	0.467	X
DAT – I	<50	X	0.469	1.000
	<100	0.469	X	1.000
	>100	1.000	1.000	X
FA – DAT	<50	X	1.000	1.000
	<100	1.000	X	1.000
	>100	1.000	1.000	X
I – BIFR	<50	X	1.000	1.000
	<100	1.000	X	1.000
	>100	1.000	1.000	X

Significant differences between groups are highlighted (ANOVA, $p \leq 0.05$)

Table 5.12: Right side measurements in a sample comparing individuals of different weight ranges for p-values using LSD

Landmark	Group			
		<50	<100	>100
A - F	<50	X	0.175	0.067
	<100	0.175	X	0.218
	>100	0.067	0.218	X
A – G	<50	X	0.818	0.839
	<100	0.818	X	0.926
	>100	0.839	0.926	X
A – I	<50	X	0.357	0.171
	<100	0.357	X	0.338
	>100	0.171	0.338	X
A – K	<50	X	0.180	0.156
	<100	0.180	X	0.427
	>100	0.156	0.427	X
D – G	<50	X	0.968	0.469
	<100	0.968	X	0.442
	>100	0.969	0.442	X
F – G	<50	X	0.854	0.379
	<100	0.854	X	0.316
	>100	0.379	0.316	X
F – I	<50	X	0.289	0.821
	<100	0.289	X	0.756
	>100	0.821	0.756	X
F – I ₃	<50	X	0.377	0.352
	<100	0.377	X	0.156
	>100	0.352	0.156	X
DAT – I	<50	X	0.156	0.797
	<100	0.156	X	0.588
	>100	0.797	0.588	X
FA – DAT	<50	X	0.718	0.901
	<100	0.718	X	0.753
	>100	0.901	0.753	X
I – BIFR	<50	X	0.722	0.956
	<100	0.722	X	0.785
	>100	0.956	0.785	X

Significant differences between groups are highlighted (ANOVA, $p \leq 0.05$)

Table 5.13. Left side measurements for a sample of varying BMI ranges for p-values using ANOVA comparisons with Bonferroni correction

Landmark					
	BMI	<18	18-25	>25	>30
A - F	<18	X	1.000	1.000	1.000
	18-24.9	1.000	X	1.000	1.000
	>25	1.000	1.000	X	1.000
	>30	1.000	1.000	1.000	X
A – G	<18	X	1.000	1.000	1.000
	18-24.9	1.000	X	1.000	1.000
	>25	1.000	1.000	X	1.000
	>30	1.000	1.000	1.000	X
A – I	<18	X	1.000	1.000	1.000
	18-24.9	1.000	X	1.000	1.000
	>25	1.000	1.000	X	1.000
	>30	1.000	1.000	1.000	X
A – K	<18	X	1.000	1.000	1.000
	18-24.9	1.000	X	1.000	1.000
	>25	1.000	1.000	X	1.000
	>30	1.000	1.000	1.000	X
D – G	<18	X	1.000	1.000	1.000
	18-24.9	1.000	X	1.000	1.000
	>25	1.000	1.000	X	1.000
	>30	1.000	1.000	1.000	X
F – G	<18	X	1.000	1.000	1.000
	18-24.9	1.000	X	1.000	1.000
	>25	1.000	1.000	X	1.000
	>30	1.000	1.000	1.000	X
F – I	<18	X	1.000	1.000	1.000
	18-24.9	1.000	X	1.000	1.000
	>25	1.000	1.000	X	1.000
	>30	1.000	1.000	1.000	X
ASC – TRNS	<18	X	1.000	1.000	1.000
	18-24.9	1.000	X	1.000	1.000
	>25	1.000	1.000	X	1.000
	>30	1.000	1.000	1.000	X
F – I ₃	<18	X	1.000	1.000	1.000
	18-24.9	1.000	X	0.273	0.649
	>25	1.000	0.273	X	1.000
	>30	1.000	0.649	1.000	X
DAT – I	<18	X	1.000	1.000	1.000
	18-24.9	1.000	X	1.000	1.000
	>25	1.000	1.000	X	1.000
	>30	1.000	1.000	1.000	X

Significant differences between groups are highlighted (ANOVA, $p \leq 0.05$)

Table 5.13. Left side measurements for a sample of varying BMI ranges for p-values using ANOVA comparisons with Bonferroni correction

Landmark		BMI	<18	18-25	>25	>30
FA – DAT		<18	X	1.000	1.000	1.000
		18-24.9	1.000	X	1.000	1.000
		>25	1.000	1.000	X	1.000
		>30	1.000	1.000	1.000	X
I – BIFR		<18	X	0.508	1.000	1.000
		18-24.9	0.508	X	1.000	1.000
		>25	1.000	1.000	X	1.000
		>30	1.000	1.000	1.000	X

Significant differences between groups are highlighted (ANOVA, $p \leq 0.05$)

Table 5.14: Left side measurements of p-values comparison of ANOVA with LSD for the sample of different BMI ranges

Landmark					
	BMI	<18	18-25	>25	>30
A - F	<18	X	0.507	0.587	0.209
	18-24.9	0.507	X	0.935	0.351
	>25	0.587	0.935	X	0.445
	>30	0.209	0.351	0.445	X
A - G	<18	X	0.256	0.209	0.279
	18-24.9	0.256	X	0.624	0.624
	>25	0.209	0.624	X	0.915
	>30	0.279	0.624	0.915	X
A - I	<18	X	0.911	0.370	0.393
	18-24.9	0.911	X	0.392	0.415
	>25	0.370	0.392	X	0.879
	>30	0.393	0.415	0.879	X
A - K	<18	X	0.537	0.491	0.680
	18-24.9	0.537	X	0.788	0.933
	>25	0.491	0.788	X	0.918
	>30	0.680	0.933	0.918	X
D - G	<18	X	0.834	0.279	0.906
	18-24.9	0.834	X	0.205	0.813
	>25	0.279	0.205	X	0.521
	>30	0.906	0.813	0.521	X
F - G	<18	X	0.892	0.221	0.223
	18-24.9	0.892	X	0.237	0.240
	>25	0.221	0.237	X	0.798
	>30	0.223	0.240	0.798	X
F - I	<18	X	0.979	0.477	0.281
	18-24.9	0.979	X	0.470	0.275
	>25	0.477	0.470	X	0.626
	>30	0.281	0.275	0.626	X
ASC - TRNS	<18	X	0.645	0.974	0.632
	18-24.9	0.645	X	0.728	0.452
	>25	0.974	0.728	X	0.699
	>30	0.632	0.452	0.699	X
F - I ₃	<18	X	0.320	0.232	0.314
	18-24.9	0.320	X	0.046	0.108
	>25	0.232	0.046	X	0.944
	>30	0.314	0.108	0.944	X
DAT - I	<18	X	0.404	0.472	0.624
	18-24.9	0.404	X	0.880	0.997
	>25	0.472	0.880	X	0.912
	>30	0.624	0.997	0.912	X

Significant differences between groups are highlighted (ANOVA, $p \leq 0.05$)

Table 5.14: Left side measurements of p-values comparison of ANOVA with LSD for the sample of different BMI ranges

Landmark					
	BMI	<18	18-25	>25	>30
FA – DAT	<18	X	0.570	0.290	0.257
	18-24.9	0.570	X	0.493	0.396
	>25	0.290	0.493	X	0.768
	>30	0.257	0.396	0.768	X
I – BIFR	<18	X	0.085	0.436	0.305
	18-24.9	0.085	X	0.536	0.982
	>25	0.436	0.536	X	0.694
	>30	0.305	0.982	0.694	X

Significant differences between groups are highlighted (ANOVA, $p \leq 0.05$)

Table 5.15. Right side measurements for a sample of varying BMI ranges for p-values using ANOVA comparisons with Bonferroni correction

Landmark					
	BMI	<18	18-25	>25	>30
A - F	<18	X	1.000	0.616	0.411
	18-24.9	1.000	X	1.000	1.000
	>25	0.616	1.000	X	1.000
	>30	0.411	1.000	1.000	X
A – G	<18	X	1.000	1.000	1.000
	18-24.9	1.000	X	1.000	1.000
	>25	1.000	1.000	X	1.000
	>30	1.000	1.000	1.000	X
A – I	<18	X	1.000	0.610	0.781
	18-24.9	1.000	X	1.000	1.000
	>25	0.610	1.000	X	1.000
	>30	0.781	1.000	1.000	X
A – K	<18	X	1.000	1.000	1.000
	18-24.9	1.000	X	1.000	1.000
	>25	1.000	1.000	X	1.000
	>30	1.000	1.000	1.000	X
D – G	<18	X	1.000	1.000	1.000
	18-24.9	1.000	X	1.000	1.000
	>25	1.000	1.000	X	1.000
	>30	1.000	1.000	1.000	X
F – G	<18	X	1.000	1.000	1.000
	18-24.9	1.000	X	1.000	1.000
	>25	1.000	1.000	X	1.000
	>30	1.000	1.000	1.000	X
F – I	<18	X	1.000	1.000	1.000
	18-24.9	1.000	X	1.000	1.000
	>25	1.000	1.000	X	1.000
	>30	1.000	1.000	1.000	X
F – I ₃	<18	X	1.000	1.000	1.000
	18-24.9	1.000	X	1.000	1.000
	>25	1.000	1.000	X	1.000
	>30	1.000	1.000	1.000	X
DAT – I	<18	X	1.000	1.000	1.000
	18-24.9	1.000	X	1.000	1.000
	>25	1.000	1.000	X	1.000
	>30	1.000	1.000	1.000	X
FA – DAT	<18	X	1.000	1.000	1.000
	18-24.9	1.000	X	1.000	1.000
	>25	1.000	1.000	X	1.000
	>30	1.000	1.000	1.000	X

Significant differences between groups are highlighted (ANOVA, $p \leq 0.05$)

Table 5.15. Right side measurements for a sample of varying BMI ranges for p-values using ANOVA comparisons with Bonferroni correction

Landmark					
	BMI	<18	18-25	>25	>30
I – BIFR	<18	X	1.000	1.000	1.000
	18-24.9	1.000	X	1.000	1.000
	>25	1.000	1.000	X	1.000
	>30	1.000	1.000	1.000	X

Significant differences between groups are highlighted (ANOVA, $p \leq 0.05$)

Table 5.16: Right side measurements of p-values comparison of ANOVA with LSD for the sample of different BMI ranges

Landmark					
	BMI	<18	18-25	>25	>30
A - F	<18	X	0.336	0.103	0.069
	18-25	0.336	X	0.298	0.167
	>25	0.103	0.298	X	0.591
	>30	0.069	0.167	0.591	X
A - G	<18	X	0.937	0.820	0.863
	18-25	0.937	X	0.857	0.893
	>25	0.820	0.857	X	1.000
	>30	0.863	0.893	1.000	X
A - I	<18	X	0.331	0.102	0.130
	18-25	0.331	X	0.299	0.293
	>25	0.102	0.299	X	0.810
	>30	0.130	0.293	0.810	X
A - K	<18	X	0.542	0.215	0.206
	18-25	0.542	X	0.386	0.328
	>25	0.215	0.386	X	0.771
	>30	0.206	0.328	0.771	X
D - G	<18	X	0.696	0.606	0.435
	18-25	0.696	X	0.420	0.553
	>25	0.606	0.420	X	0.301
	>30	0.435	0.553	0.301	X
F - G	<18	X	0.746	0.434	0.351
	18-25	0.746	X	0.301	0.263
	>25	0.434	0.301	X	0.761
	>30	0.351	0.263	0.761	X
F - I	<18	X	0.196	0.404	0.751
	18-25	0.196	X	0.957	0.713
	>25	0.404	0.957	X	0.776
	>30	0.751	0.713	0.776	X
F - I ₃	<18	X	0.559	0.750	0.311
	18-25	0.599	X	0.962	0.188
	>25	0.750	0.962	X	0.263
	>30	0.311	0.188	0.263	X
DAT - I	<18	X	0.194	0.661	0.828
	18-25	0.194	X	0.564	0.572
	>25	0.661	0.564	X	0.910
	>30	0.828	0.572	0.910	X
FA - DAT	<18	X	0.855	0.803	0.832
	18-25	0.855	X	0.699	0.754
	>25	0.803	0.699	X	0.984
	>30	0.832	0.754	0.984	X

Significant differences between groups are highlighted (ANOVA, $p \leq 0.05$)

Table 5.16: Right side measurements of p-values comparison of ANOVA with LSD for the sample of different BMI ranges

Landmark					
	BMI	<18	18-25	>25	>30
I – BIFR	<18	X	0.914	0.550	0.760
	18-25	0.914	X	0.566	0.797
	>25	0.550	0.566	X	0.879
	>30	0.760	0.797	0.879	X

Significant differences between groups are highlighted (ANOVA, $p \leq 0.05$)

Table 5.17: Measurements for the anterolateral approach comparing gender (males and females)

Landmark	Group	N	Mean	SE	95% Confidence Interval		t-test, p-value
J – K	Female	3	97.6667	10.68228	51.7045	143.6288	0.337
	Male	17	103.4706	1.82531	99.6011	107.3401	
	Total	20	102.6000	2.10063	98.2033	106.9967	
J – N	Female	3	93.3333	17.94745	16.1117	170.5550	0.422
	Male	17	86.8824	1.81676	83.0310	90.7337	
	Total	20	87.8500	2.77989	82.0316	93.6684	
K – M	Female	3	51.0000	11.93035	-0.3322	102.3322	0.737
	Male	17	48.4706	2.47505	43.2237	53.7175	
	Total	20	48.8500	2.58363	43.4424	54.2576	
K – N	Female	3	21.3333	4.40959	2.3604	40.3062	0.905
	Male	17	21.8824	1.74660	18.1797	25.5850	
	Total	20	21.8000	1.57881	18.4955	25.1045	
M – N	Female	3	29.6667	6.35959	2.3035	57.0898	0.498
	Males	17	25.7059	2.15189	21.1441	30.2677	
	Total	20	26.3000	2.01455	22.0835	30.5165	

Significant differences between groups are highlighted (t -test, $p \leq 0.05$)

Table 5.18: Measurements for the anterolateral approach comparing differences sides (left and right sides)

Landmark	Group	N	Mean	SE	95% Confidence Interval		t-test, p-value
J – K	Right	6	99.6667	3.50872	90.6472	108.6861	0.375
	Left	14	103.8571	2.60358	98.2324	109.4818	
	Total	20	102.6000	2.10063	98.2033	106.9967	
J – N	Right	6	84.5000	3.61248	75.2138	93.7862	0.445
	Left	14	89.2857	3.66814	81.3612	97.2103	
	Total	20	87.8500	2.77989	82.0316	93.6684	
K – M	Right	6	45.8333	3.71857	36.2744	55.3922	0.460
	Left	14	50.1429	3.35100	42.9035	57.3823	
	Total	20	48.8500	2.58363	43.4424	54.2576	
K – N	Right	6	17.6667	0.95452	15.2130	20.1203	0.086
	Left	14	23.5714	2.06146	19.1179	28.0249	
	Total	20	21.8000	1.57881	18.4955	25.1045	
M – N	Right	6	26.5000	2.74165	19.4524	33.5476	0.950
	Left	14	26.2143	2.68937	20.4042	32.0243	
	Total	20	26.3000	2.01455	22.0835	30.5165	

Significant differences between groups are highlighted (t -test, $p \leq 0.05$)

Chapter 6

Discussion

Hip arthroplasty encompasses a variety of elements in order for the operating procedure to be successful. Surgeons not only look at the approach they will choose but also at different implantation devices with their merits and demerits. The approach chosen by the surgeon is usually one that they are comfortable with but consideration should also be given to the best possible outcome for the patient. In the South African context, the surgical aspect of minimally invasive total hip arthroplasty is usually performed using the posterior approach. Literature states and has shown in a variety of instances that this approach, although the one the surgeon is familiar and comfortable with, is not necessarily the ideal approach for the patient (Sköldenberg *et al.*, 2010). When the posterior approach is used, a higher instance of dislocations is noted when compared to the anterior and/or anterolateral approach (Mattingly, 1995; Sköldenberg *et al.*, 2010). It is therefore important for future patients, that doctors overcome the high learning curve that exists when the anterior approach is applied and move towards the use of the anterior approach to hip arthroplasty. Proper knowledge of the anatomy underlying the LCFA and the LFCN along with their variations and branching patterns, is pivotal to overcome possible complications that may result.

6.1. Comparison between the anterior and anterolateral approach

The anterior approach to hip arthroplasty is said to have changed the scope of medicine in the orthopaedic world (Gomez and Morcuende, 2005). In the past, patient recovery was known to take time. Mobility of the patient was regained a number of days after the replacement of the hip was performed (Bal, 2008; Vivek *et al.*, 2009). Another area of concern for orthopaedic surgeons was the number of revisions that needed to be performed due to dislocations of various implantation devices. Since the attempt to reintroduce the anterior approach to clinical settings, some advantages, not previously seen in the surgery of the hip were noted (Mattingly, 1995; van Dijk *et al.*, 2009). The advantages of the anterior approach include lower dislocations rates and faster patient recovery post-surgery. The other advantage include quicker recovery rates post-surgery due to the muscle being stretched and not transected as in the anterolateral technique. Muscles that are stretched heal faster, therefore resulting in patients gaining mobility in as fast as six hours post-surgery (Nakata *et al.*, 2009; Gang *et al.*, 2010; Moskal *et al.*, 2014). In the South African context, the outcome of faster turnaround times would be

beneficial to the health system as patients could be discharged at a faster rate, making more beds available, resulting in more surgeries being performed.

The anterolateral approach is advantageous for better exposure of the hip joint while still recording fewer dislocation rates as compared to the posterior approach. However, the anterior approach still remains the best approach to hip arthroplasty. This notion is supported by the findings made in various studies (Bal, 2008; Sariali *et al.*, 2008; Nakata *et al.*, 2009; Moskal *et al.*, 2014).

The current study simulated the surgical incisions on the cadavers (Figure 6.1) with the exception of the incision length and muscles transacted. For the anterolateral approach simulation, the incision was made as per the surgical dissections and the area around the incision dissected. The current study revealed no significant difference in the anterolateral approach for distances measured from the incision site to the superior gluteal vessels, and the distances from the incision site to the various anatomical landmarks (ASIS and the greater trochanter).

In the study it was also noted that concerns relating to the injury LFCN and LCFA during surgery using the anterior approach, could be circumvented when the orthopaedic surgeon was familiar with the surgical method and variations relating to the branching patterns of both the LFCN and LCFA.

The anterior approach simulation was a deviation from the surgical procedure as the skin was first reflected and transection of the sartorius muscle and the rectus femoris muscle followed. The incisions for the anterior approach were made in order to access the anterior capsule of the hip joint and the LCFA.

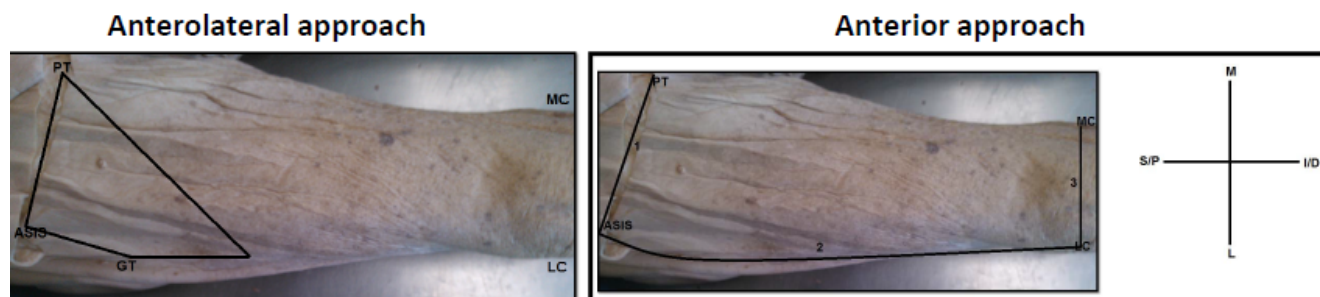


Figure 6.1: Anterior view showing cadaver in the supine position. The comparison between the anterior and the anterolateral approach is showing the incisions made during the anterior and the anterolateral data collection phase. Key: I-Inferior; D-Distal; M-Medial; L-Lateral; S/P-Superior, Proximal; A-Anterior; P-Posterior; FA-Femoral Artery; DA-Profunda femoris artery; PT-Pubic Tubercle

6.1.1. The anatomy underlying MIS-THA using the anterior approach

The current study investigated the anatomy underlying MIS-THA with special attention paid to the main structures of concern being the LCFA and the LFCN. In this study it was noted that when the incisions were made as described by Smith-Petersen (1949) and a few modifications of this approach, the vessels of concern could be avoided and not damaged. The incisions in the current study were made with the aim of exposing the anterior capsule of the hip joint along with the LFCN and LCFA with its branches. The incisions were made along the lines indicated in Figure 6.1 for the anterolateral and anterior approaches. Variations and deviation from the surgical procedure was necessary, which entailed transecting the sartorius muscle and the rectus femoris muscle for the anterior approach, in order to clearly expose the anterior capsule of the hip joint and the branches of the LCFA.

During the simulation on the cadaver by the orthopaedic surgeon, it was noted that in all 21 incisions made, the LFCN was a safe distance away from the incision site. The incisions were made along the line connecting the lateral aspect of the ASIS with the greater trochanter. The incision site was determined by an imaginary line drawn 20 mm lateral and inferior to ASIS, and 20 mm lateral to the greater trochanter. The dissection of the area around the incision site, revealed that in all 21 incisions made the LFCN or any of its branches had not been damaged, this was then considered a safe distance.

The cadavers included in this portion of the study were both male and female cadavers of various BMI groups (less than 18 kg/m², between 18-25 kg/m², higher than 25 kg/m² but equal and not higher than 30 kg/m²). This aspect of the research shows that when the correct anatomical structures are palpated and clearly marked prior to making incisions, thigh numbness as a result of injury to the LFCN could be avoided as the incisions made would avoid injury to the LFCN or any of its branches and the LCFA.

6.1.2. Distance between anatomical landmarks and the neurovascular structures

The current study revealed the distance from various anatomical landmarks to be similar when the left and right measurements were compared. The distances referred to in this section of the study relate to the distances from the ASIS, pubic tubercle, anterior capsule of the hip joint and medial border of the rectus femoris muscle to the LFCN and the LCFA.

In the comparison per age, significant differences were detected for the mean distances from the pubic tubercle to the LCFA and the mean distance from the pubic tubercle to the straight head of the rectus femoris muscle. The mean distances for age refers to the sample of individuals who are 50 years old and younger and the sample older than 50 years. The measurements for the distances from the pubic tubercle to the LCFA revealed the p-value to be significant for left side measurements. Therefore, caution must be exercised when using the pubic tubercle as an anatomical landmark in the attempt to determine the location of the LCFA, as the distances of the LCFA in relation to the pubic tubercle may vary. The LCFA was measured at the point where it is branching from the profunda femoris artery or from the femoral artery. In the current study, we found the LCFA branching from the profunda femoris artery in 74/90 (82.2%) of the hips dissected. These findings compare well with findings made by Massoud and Fletcher (1997) and Prakash *et al.* (2010) found this percentage to be 81% and 81.25%, respectively (Massoud and Fletcher, 1997; Prakash *et al.*, 2010). In the remaining 16/90 (17.8%) hips, the LCFA branched directly from the femoral artery. Previous literature examining the origin of the LCFA omits the distance from the LCFA in relation to the ASIS or the pubic tubercle. The implications of attempting to use the pubic tubercle as a landmark for locating the LCFA, could result in vascular injuries during THA procedures.

In the comparison per age, statistical significance was detected for the mean distance from the pubic tubercle to the straight head of the rectus femoris muscle. The measurement of the rectus

femoris was made on the medial border of the straight head of the rectus femoris muscle. This significance denotes possible changes that the muscle may undergo with age. The study by Mahood *et al.* (2008) alludes to the changes in the quadriceps femoris muscle. Even though the study conducted by Mahood *et al.* (2008) show significant atrophy to the vastus lateralis muscle compared to the other quadriceps muscle, the current study shows evidence of age related muscle degeneration (Mahood *et al.*, 2008). In the study by Hapa *et al.* (2013), one of the factors focused on is on the broadness of the origin of the straight head of the rectus femoris muscle (Hapa *et al.*, 2013). Hapa *et al.* (2013) studied the tendon of the straight head of the rectus femoris muscle, at the origin on the anterior inferior iliac spine in the sample of cadavers in the age ranges 14 years to 52 years (Hapa *et al.*, 2013). The findings made by Hapa *et al.* (2013) relating to the broadness of the area of insertion of the straight head of the rectus femoris muscle, may possibly account for the significance detected in the distance from the pubic tubercle to the straight head of the rectus femoris in the current study. The variation in the area of attachment of the straight head of the rectus femoris muscle and the age related degeneration of the muscle could possibly account for the significance detected (Mahood *et al.*, 2008; Hapa *et al.*, 2013).

Significant differences for measurements from the ascending/descending branch of the LCFA to the branching of the ascending/descending branch into an ascending/descending branch and a transverse branch were detected when males and females in the sample were compared as well as comparisons made in the different weight ranges ($P=0.017$). The current study findings revealed that the transverse branch of the LCFA is not consistent in its area of origin. The current study noted that in 59/90 (65.6%) cases, the transverse branch branched from ascending branch of LCFA while in 9/90 (10%) hips dissected, the transverse branch branched from the descending branch of the LCFA. Our results also showed that the transverse branch of the LCFA was not always visible as was the case is 4/90 (4.4%) hips dissected, where no transverse branch of the LCFA was found. In the literature reviewed regarding the origin of the LCFA and its variations, no study could be found that investigated the distance from the ascending/descending branch of the LCFA to the branching of the ascending/descending branch into an ascending/descending branch and a transverse branch. The origin of the transverse branch of the LCFA has also not been investigated by previous studies, creating a challenge in the attempt to compare the current study to previous research.

In the category comparing individuals of varying BMI ranges, significant differences were detected in the sample of individuals in the BMI ranges between 18-25 kg/m² and those

individual of the BMI higher than 25 kg/m² but equal and not higher than 30 kg/m². These significant differences were the left side measurements for distances from the anterior capsule of the hip joint to the branching of the LCFA (from the profunda femoris artery/the femoral artery). The current study revealed the branching of the LCFA from the profunda femoris artery to be apparent in 74/90 (82.2%) of the hips dissected. In their case report study, Balachandra *et al.* (2011) found the origin of the LCFA to be the profunda femoris artery and to a lesser degree the femoral artery, comparable to previous studies (Balachandra *et al.*, 2011). The study is consistent with the findings made by Dixit *et al.* (2001), Choi *et al.* (2007) and Prakash *et al.* (2010) (Dixit *et al.*, 2001; Choi *et al.*, 2007; Prakash *et al.*, 2010). In the findings by Dixit *et al.* (2001), the LCFA was found branching from the profunda femoris artery in 83.34% in their study cases. Choi *et al.* (2007) and Prakash *et al.* (2010) found this percentage to be 86.8% and 81.25%, respectively. In 16/90 (17.8%) LCFA branched from the femoral artery. These findings are comparable with the study by Balachandra *et al.* (2011). Similar findings were made by Dixit *et al.* (2001), who found this to be the case in 16.66% of their study sample. Choi *et al.* (2007) found this percentage to be slightly lower, at 13.2% in their study. In the study by Üzel *et al.* (2008) this percentage stands at 22.7%. The current study compares closely with the findings by Prakash *et al.* (2010) who found this average to be 18.75% in their study sample.

The average distance from the ASIS to the LFCN was noted as 13.6 mm on the left side and 12.6 mm on the right side of the total hips dissected. The measurement of the LFCN in relation to the ASIS was taken at the point where the LFCN courses posterior to the inguinal ligament, as no interruption to the original location of the nerve had occurred at the point. Ray *et al.* (2010) found the LFCN to course 25 mm medially from the ASIS in 72% of their study cases (Ray *et al.*, 2010). The findings made in this study relate closely to Mischkowski *et al.* (2006), in their study the average distance from the ASIS to the point where the nerve courses posterior to the inguinal ligament, was found to equate to 14.99 mm (Mischkowski *et al.*, 2006).

6.1.3. Distance between anatomical landmarks and other soft tissue

The current study further investigated the distances between the anatomical landmarks and other soft tissue relating to the anterior compartment of the thigh. The soft tissue in this section refer to the rectus femoris muscle and the anterior capsule of the hip joint. In the current study,

significant differences were detected for distances measured from the anatomical landmarks to other soft tissue, when the sample for males and females was compared.

In the comparison of the male and female sample of the study, significant differences were detected in the mean distance from the pubic tubercle to the anterior capsule of the hip joint on the left side. These findings showed that distance from the pubic tubercle to the anterior capsule of the hip joint was variable in the male and female sample. The findings of the study are consistent with the findings made by Papaloucas *et al.* (2008). In their study of sexual dimorphism in the Greek sample, Papaloucas *et al.* (2008) highlight the distance from the pubic tubercle to the anterior rim of the acetabulum to be smaller in males in comparison to the female sample (Papaloucas *et al.*, 2008). The distance taken in the anterior capsule of the hip joint was measured by dividing the iliopsoas muscle into three with imaginary lines. The anterior capsule of the hip joint was measured on the middle third of the lateral border of the iliopsoas muscle, as it is seen in the anterior compartment of the thigh.

The *t*-test revealed significant differences in the measurements on the right side for comparison between male and female cadavers in the study sample. The significant differences were for the mean distance of measurements taken from the pubic tubercle to the straight head of the rectus femoris muscle. In the study by Pellico and Camacho (1992), significant differences were detected when distances from the pubic tubercle to the superior inferior iliac spine were compared in males and females (Pellico and Camacho, 1992). The findings made by Pellico and Camacho (1992) are comparable with the current study, as the current study detects statistical significance for the measurement from the straight head of the rectus femoris muscle to the pubic tubercle. The straight head of the rectus femoris muscle originates from the anterior inferior iliac spine (Moore and Dalley, 1999).

In the other measurements taken, the current study revealed the average distance from the pubic tubercle to the ASIS on the left side to be 106.7 mm and the right side to be 107.2 mm, for combined male and female measurements. In the comparison between male and female measurement on the left side and the right side, the measurements were found to vary slightly. The measurements found for the distances from the pubic tubercle to the ASIS in the male sample, was found to equate to 107.6 mm on the left side and 107.4 mm on the right side. The measurements taken for the female sample, show these findings to be 102.5 mm on the left side and 100.22 mm on the right side. In the study by Kanabur (2012), a comparison is made for the distances from the pubic tubercle to the ASIS in the male and female sample. In his findings,

Kanabur (2012) also notes a slight variation between left and right measurement in the male and female sample, as found in the current study. The findings made by Kanabur (2012), the average left side distance equated to 107.5 mm in males and 98.0 mm in females. The average distances are noted as 109.4 mm in males and 101.0 mm in females (Kanabur, 2012). The findings by Kanabur (2012) and the findings from the current study show the average distance from the pubic tubercle to the ASIS to be slightly higher in the male sample (Kanabur, 2012).

6.2. Course and variation of LFCN

The LFCN is formed from the L2-L3 posterior rami and courses over the iliacus muscle in the false pelvis. The LFCN exits the abdomen by traversing posterior to the inguinal ligament, coursing on the medial aspect of the ASIS (Carai *et al.*, 2009). The LFCN as seen in the anterior compartment of the thigh, crosses the sartorius muscle between the tensor fascia latae muscle and the iliacus fascia (Moore and Dalley, 1999; Ray *et al.*, 2010). The LFCN provides cutaneous innervation to the lateral and anterolateral aspect of the thigh, injury to the LFCN may result in thigh numbness post-surgery (Bal, 2008). Variations in the anatomy and the branching pattern of the LFCN were noted in previous studies. Ray *et al.* (2010) found the LFCN to course 25 mm medially from the ASIS in 72% of their study cases. The current study found the course of the LFCN to be 13.6 mm from the ASIS on the left side in 40/45 (89%) hips dissected and 12.6 mm from the ASIS on the right side in 45/45 hips dissected. Other studies have also reported the course of the LFCN to cross lateral to the ASIS, these ranges were found to be between 0-19% (Mischkowski *et al.*, 2006; Ray *et al.*, 2010). The current study revealed that none of the LFCNs were found running on the lateral aspect of the ASIS, however, in 5/45 (11%) hips dissected on the left side the LFCN was found coursing directly over the ASIS.

The branching pattern of the LFCN has been documented to vary, with as many as four branches documented. In nearly all the cases studied, the same number of branches was documented on the left and the right side (Carai *et al.*, 2009; Martins *et al.*, 2011). The current study did not focus on the branching pattern of the LFCN due to the shortages of cadaver material. The cadavers included in the study had been superficially dissected by undergraduate students, the LFCN was left uninterrupted at the inguinal ligament however, some of the branches had been transected. The LFCN measurement used in the current study was taken at the point where the nerve passes posterior to the inguinal ligament, or traverses the ASIS to

reach the anterior and anterolateral aspect of the thigh. Therefore, it was not possible to study the branching pattern of the LFCN but measurements could be taken in its course relating to the inguinal ligament.

6.3. Course and variation of LCFA

Anatomically, the LCFA is described by textbooks as a lateral branch of the profunda femoris artery (Moore and Dalley, 1999). The profunda femoris artery is known to be the largest branching of the femoral artery in the anterior division of the thigh. The LCFA passes laterally between the anterior and posterior divisions of the femoral nerve on the posterior aspect of the sartorius muscle and the rectus femoris muscle. The LCFA is then seen to branch into three known branches namely; the ascending, transverse and descending branches (Standring, 2005). The course of the LCFA in the current study was consistent with literature, the variations however appeared when assessing the branching pattern of the LCFA along with the number of branches resulting from the LCFA's branching. In the current study, it was noted that in 15.6% of the cases the LCFA had four branches, while in 11.1% of the cases the LCFA had five branches. As many as six branches of the LCFA were noted in 3.3% of the cases. The percentage that was consistent with textbook descriptions (Standring, 2005) of the number of branches given by the LCFA was 70% of the cases in the study sample, which adhered to branching pattern resulting in the ascending, transverse and descending branch.

The current study also deviated from Standring (2005) when studying the origin of the LCFA. The LCFA originated from the profunda femoris artery in 82.2% of the cases. These finding is consistent with the studies by Dixit *et al.* (2001), Choi *et al.* (2007) and Prakash *et al.* (2010) (Dixit *et al.*, 2001; Choi *et al.*, 2007; Prakash *et al.*, 2010). Dixit *et al.* (2001) found this percentage to be 83.34% in their study. Choi *et al.* (2007) and Prakash *et al.* (2010) found this percentage to be 86.8% and 81.25%, respectively. The current study also revealed some variations that differed from published literature. In 1% of the total hips dissected, the femoral artery was found to be branching into an “accessory” ascending and descending branch, even though the LCFA had already branched into the three branches. The “accessory” branches given off by the femoral artery were following the path of the ascending and descending branches of the LCFA. Another anomaly was found in 1% where the ascending branch was branching from the profunda femoris artery but the descending branch was branching from the femoral artery, with no visible transverse branch noted. A case was noted in 1% of the study

sample, where the descending branch was seen as a direct branch of the profunda femoris artery, independent of the LCFA. The descending branch of the LCFA was also found branching directly from the femoral artery in 1% of the study sample.

In the 1% of the study sample, the ascending branch of the LCFA was noted branching from the femoral artery and the descending and transverse branches were branching from the LCFA. The LCFA in this instance, originated from the profunda femoris artery. This variation showed a low prevalence as it was noted in only 1% of the study population. The vessel however, was found to follow a similar course as characteristic of the ascending branch of the LCFA. This variation is not deemed a hindrance when the anterior approach is used as the artery followed the known course of the ascending branch of the LCFA. These observations are comparable with findings made by Üzel *et al.* (2008) who found this variation in 1.8% of their study sample (Üzel *et al.*, 2008). Fukuda *et al.* (2005) found the percentage to equate to 4.6% of the study sample (Fukuda *et al.*, 2005).

6.3.2. Branching patterns of LCFA

The LCFA is an artery branching from the profunda femoris artery and later branching into the ascending, descending and transverse branches. In the current study however we found that the LCFA does not always adhere to this branching pattern or area of origin. The current study, the LCFA originated from the DAT in 74/90 cases (82.2%). This fact is comparable and similar to the findings made by Prakash *et al.* (2010) who in their study found the average to be 81.25%. Previous studies conducted also compare well with the current study, Dixit *et al.* (2001) found this percentage to be 83.34% while Fukuda *et al.* (2005) obtained his results using angiographs in 78.6% of the cases investigated. Choi *et al.* (2007) and Üzel *et al.* (2008) found these percentages to be 86.8% and 77.3%, respectively.

The current study also found that not all the LCFAs investigated originated from the profunda femoris artery, 16/90 (17.8%) LCFA branched from the femoral artery. The findings of the current study also compare well with previous studies conducted, which show the origin of the LCFA to be from the femoral artery. Dixit *et al.* (2001) found this to be the case in 16.66% of their study cases, while Choi *et al.* (2007) found this percentage to be slightly lower, at 13.2% in their study. In the study by Üzel *et al.* (2008) this percentage was 22.7%. The current study relates closely with the findings by Prakash *et al.* (2010) who found this average to be 18.75%

in their study. In their study using angiographs, Fukuda *et al.* (2005) found this percentage to equate to 21.4%.

6.4. Limitations of the study

During the data collection phase of the study, several limitations were encountered. The methods used for the data collection of this study were mainly to accommodate the fixed and hardened nature of cadaver tissue. The result of the nature of cadaver tissue was seen in muscles being transected which under clinical settings would have been preserved and only stretched. Difficulty was encountered in palpation of the various anatomical landmarks prior to incising the skin, this difficulty is a result of the hardened cadaver tissue.

Though 90 hips were dissected not all the measurements for height, weight and BMI were available. The collection of data was also restricted by the limited number of cadavers, which in some instances led to data being collected on one side of the cadaver and not in both hips. The cadavers on whom this data was collected are used by medical and allied health sciences anatomy students, as a result some structures such as the femoral artery and the LFCN were transected during the pelvis dissections. The cadavers on whom the LFCN and/or femoral artery had been transected could be used by collecting data in the unaffected limb.

The effect of cadaver shortages was experienced again during the data collection for the anterolateral approach, during this stage only 20 hips were available for data collection.

6.5. Future direction of the study

In the future, the study will look at “fresh material” and compare the results with the findings made in this study. The LCFA, LFCN and their branching patterns will be compared to the findings in “fresh material”.

6.6. Clinical relevance of the study

The anatomy of the LCFA is taught such that only three branches are highlighted. The branching pattern of LCFA is communicated as the ascending, transverse and descending branches. In the study this was not always the case. The study revealed that in 15.6% of the cases the LCFA had four branches, in 11.1% of the cases the LCFA had five branches. The

current study revealed that as many as six branches of the LCFA could be found and this was seen in 3.3% of the study sample.

The ascending branch of the LCFA is an area of concern for orthopaedic surgeons using the anterior approach, this is supported in the study, and our findings revealed that in 65.6% of the study sample the ascending branch of the LCFA gave rise to the transverse branch. Ligation of the ascending branch of the LCFA during hip arthroplasty would therefore require caution, as the transverse branch might be branching from the LCFA. In 1% of the sample, the ascending branch was noted to be branching from the femoral artery while the transverse and descending branches of LCFA originated from the profunda femoris artery.

It is of clinical significance that the orthopaedic surgeon performing surgery using the anterior approach is aware of variations in the branching pattern of the LCFA, to avoid complications and possible intra-operative bleeding.

Chapter 7

Conclusion

In conclusion, the anterior approach, as indicated by different studies, is better for patient outcome, as the procedure does not entail transecting any muscles, which in turn reduces the length of hospitalisation and allows for faster mobility of the patient, after surgery (Trousdale, 2004; Bal, 2008; Brown *et al.*, 2008). It has been noted by a few surgeons, that the high learning curve that exists in the use of the anterior approach can be overcome with time, when the orthopaedic surgeon performing the surgery elects to use the anterior approach on numerous occasions (Keggi and Grey, 2005; Bal, 2008; Brown *et al.*, 2008). The current study supports this notion as it was found that two main vessels of concern, the LCFA and the LFCN could be avoided when the incisions are made 2 cm lateral and distal to the ASIS and 2 cm lateral and distal to the greater trochanter of the femur. The incisions made along these lines showed that in the 21 hips on whom the incisions were simulated, no nerves were transected. It was therefore evident from the incisions made by the orthopaedic surgeon that when the anterior approach method is followed as per the guidelines indicated (Keggi and Grey, 2005; Bal, 2008; Brown *et al.*, 2008), that the LFCN or any of its branches would not be damaged. In the data analysed looking at the anatomy of the LCFA, it was evident that most of the variations identified in our study were comparable to current literature. The study revealed that in 17.8% of the cases the origin of the LCFA was from the femoral artery and only 82.2% of the branching came directly off the profunda femoris artery. This fact is comparable with studies conducted by Dixit *et al.* (2001), Choi *et al.* (2007) and Prakash *et al.* (2010) (Dixit *et al.*, 2001; Choi *et al.*, 2007; Prakash *et al.*, 2010). In the current study, the course of the LFCN was found to be 1.3 cm from the ASIS on the right side and 1.4 cm from the ASIS on the left side. In 5.6% of the cases, the course of the LFCN was on the ASIS.

The results of the anterolateral approach indicate that due to the transection of the anterior one third of the gluteus medius muscle, the hip joint could be visualised better as indicated by previous studies (Gang *et al.*, 2010). The current study did not find any statistical significance from the incision site to the superior gluteal vessels, this indicates that the superior gluteal vessels could be avoided when the incisions were made as per Hardinge method (Hardinge, 1983). The concern that exist however, is the patient outcome when the anterior approach is used. In previous studies it was noted that patients on whom MIS-THA was performed using the anterior approach could walk in as little as six hours post-surgery (Keggi and Grey, 2005; Bal, 2008; Brown *et al.*, 2008). These studies showed that the amount of pain experienced by

the patients was also minimal compared to the patient for the anterolateral approach, due to the muscle being stretched and not transected, therefore causing less pain (Nakata *et al.*, 2009; Gang *et al.*, 2010; Moskal *et al.*, 2014).

The study supports this notion, even though cadaver material was used for the data collection phase of our study, it is known that overstretched tissue recovers faster than incised tissue (Nakata *et al.*, 2009; Gang *et al.*, 2010; Moskal *et al.*, 2014). The evidence of the notion relating to faster recovery of muscle tissue can be seen in patients on whom hip replacement was performed using the anterior approach. The patients showed faster recovery signs post-surgery, when compared to groups where the anterolateral or posterior approach to hip arthroplasty was used. This fact is important in the South African context, as the patients could be discharged sooner, resulting in a decrease in the costs to the health care system. This would also mean more surgeries could be performed as more beds would be available.

The variations that exist in the LCFA and LFCN are important to note. Knowledge of the variations would make the anterior approach a better option for the patient when the high learning curve is overcome.

In conclusion, our study supports the findings made by Bal (2008), who after switching from using the anterolateral approach to the anterior approach noted faster recovery rates, speedier regain of mobility by the patients and lower dislocation rates (Bal, 2008). Similar findings were made by Sariali *et al.* (2008), Nakata *et al.* (2009), Bergin *et al.* (2011) and Moskal *et al.* (2014) (Sariali *et al.*, 2008; Nakata *et al.*, 2009; Bergin *et al.*, 2011 and Moskal *et al.*, 2014). Bal (2008) noted that the LCFA and the LFCN could be avoided with thorough knowledge of the region and operating technique.

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The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.

- FWA 00002567, Approved dd 22 May 2002 and Expires 20 Oct 2016.
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UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences Research Ethics Committee

31/07/2014

**Approval Certificate
New Application**

Ethics Reference No.: 274/2014

Title: The comparative anatomy of the minimally invasive total hip arthroplasty one incision method using the anterior and anterolateral approach.

Dear Mrs Nkhensani Mogale

The **New Application** as supported by documents specified in your cover letter for your research received on the 4/07/2014, was approved, by the Faculty of Health Sciences Research Ethics Committee on the 30/07/2014.

Please note the following about your ethics approval:

- Ethics Approval is valid for 2 years.
- Please remember to use your protocol number (**274/2014**) on any documents or correspondence with the Research Ethics Committee regarding your research.
- Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, or monitor the conduct of your research.

Ethics approval is subject to the following:

- The ethics approval is conditional on the receipt of 6 monthly written Progress Reports, and
- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

We wish you the best with your research.

Yours sincerely

Dr R Sommers; MBChB; MMed (Int); MPharMed.

Deputy Chairperson of the Faculty of Health Sciences Research Ethics Committee, University of Pretoria

The Faculty of Health Sciences Research Ethics Committee complies with the SA National Act 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 and 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes 2004 (Department of Health).

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