SURGICAL ANATOMY OF FEMORAL NERVE(S) IN FORMALIN PREFIXED CADAVERS IN AN ADULT KENYAN POPULATION

BY

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DECLARATION

Candidate's Declaration

The candidate declares that this research thesis is personal original work and has not been submitted elsewhere for any academic purpose or research in any institution of higher learning.

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DEDICATION

This study is dedicated to the donors of cadavers to the Department of Human Anatomy, School of Medicine, Moi University.

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Foremost, I would like to express my sincere gratitude to my supervisors for the continuous support of my research thesis, for their patience, motivation, enthusiasm, and immense knowledge. I would like to thank my family for supporting me spiritually throughout. I would like to thank my colleagues for their unyielding support throughout the duration of this research.

LIST OF ABBREVIATIONS AND ACRONYMS

A.S.I.S Anterior Superior Iliac Spine

E.M.G Electromyography

M.T.R.H Moi Teaching and Referral Hospital

O.R.I.F Open Reduction and Internal Fixation

T.F.L Tensor Fascia Lata

T.H.A Total Hip Arthroplasty

ABSTRACT

Background: Variations involving femoral nerve have been described in literature. This nerve is the largest branch of the lumbar plexus arising from the posterior division of the ventral rami, 2nd- 4th nerve roots. It has motor innervation to hip flexor, knee extensors, while sensory to medial and anterior aspects of the thigh. Risks of insults to nerve can be non-iatrogenic (trauma), and iatrogenic (approaches and procedures to the acetabulum, pelvis and proximal femur, when mostly not cautious, and unaware of variant anatomy). The study aimed at providing precise description of variant anatomy of nerve, hence will help surgeons avoid iatrogenic insults.

Objective: To describe the anatomical course and length of the femoral nerve and its main branches in relation to the inguinal ligament.

Methods: Study site was Human Anatomy Laboratory, Moi University School of Medicine, using anatomic descriptive cross-sectional study design. It involved a selected population of fifty six (56), both male and female formalin prefixed adult cadaveric specimens. Included were adult pelvic and lower limb cadavers without gross evidence of fracture, pathology or prior surgery, while excluded were deformed or mutilated cadavers. Dissection was done to expose femoral nerve and its branches according to Cunningham's Manual of Practical Anatomy 15th Edition. The length of the femoral nerve in relation to the inguinal ligament and its bony attachments, and the patterns of distribution of main branches in the regions were defined. Measurements were taken using Vernier callipers (accuracy to 0.01mm) and documented in the structured data collection forms. Coloured photographs of the nerves and branches were taken and also documented. Measurements were analysed using IBM SPSS Statistics Version 20.0.0. Results presented in form of tables, text, graphs and photographs.

Results: Males- 35 (Left=17, Right=18); Females- 21(Left=7, Right=14). Femoral nerve location- lateral to mid-inguinal point: 53.02 mm (SD 14.59) from the ipsilateral anterior superior iliac spine (ASIS) and 72.87mm (SD 19.75) from the pubic symphysis. Nerve trunk in relation to inguinal ligament measured: 47.85mm (SD 13.719) from the psoas muscle proximally and branched 29.32 mm (SD 14.239) distally. Innervations and branches: quadriceps in all specimens (Posterior); Sartorius muscles (Anterior), with noted variability in individual muscles. Branching pattern variations: 6 limbs (10.71%) at ligament level, 2(3.57%) limbs had a more proximal, while one nerve was split by a slip from the psoas muscle and then united 25.88mm proximal to ligament. The variations in sex and measurements were not statistically significant ($p > 0.05$).

Conclusion: The anatomical course, length and branches of the femoral nerve in relation to inguinal ligament in adult Kenyan population concur to great extent with described anatomic studies with some noted variability.

Recommendations: Surgeons should be aware of the anatomic variations of femoral nerve and be cautious when operating in the zones traversed by the nerve.

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CHAPTER ONE: INTRODUCTION

1.1 Background Information

The femoral nerve is the largest branch of the lumbar plexus arising from the posterior division of the ventral rami of L2, L3 and L4 nerve roots (occasionally receiving L1 and L5 spinal nerve roots). In the retroperitoneal space, it traverses between the iliacus and psoas muscles. The femoral nerve emerges as a whole nerve on the anterolateral aspect of the psoas major muscle approximately 4cm proximal to the inguinal ligament(Davis, Bae, Mok, Rasouli, and Delamarter, 2011; Gindha, Deepti, Subhash, and Usha, 2015; Oyedun, Rukewe, and Fatiregun, 2014; Swami, V, and D, 2020).

It traverses beneath the inguinal ligament to emerge within the femoral triangle lying lateral to the femoral sheath. The nerve emerges in a groove between the iliacus and psoas muscles at the midpoint of the inguinal ligament where its course is directly anterior to the capsule of the hip joint separated by the iliopsoas tendon(Standring and Gray, 2008). The femoral triangle is a descriptive anatomical space bordered by the inguinal ligament (superiorly/base), adductor longus (medially) and sartorius (laterally). The femoral nerve divides 2-4cm (1-1.5inches) below the mid-point of the inguinal ligament into the anterior and posterior branches. The anterior branch has motor (pectineus and sartorius muscles) and sensory (intermediate and medial cutaneous femoral nerves) branches. The posterior branch has motor (quadriceps femoris) and sensory (saphenous nerve) branches(Cunningham and Romanes, 1995).

Watson et al., (2014) identified anatomical variations of the femoral nerve in relation to the bony attachments of the inguinal ligament among different ethnic and demographic populations. The mean distance from the anterior superior iliac spine to the femoral nerve was 28.67 mm (range, 6.2 to 53.3 mm). However, the femoral nerve vector varied between Caucasians and African Americans (p=0.04) as well as among Hispanics and African Americans (p=0.04).

Anloague and Huijbregts (2009) demonstrated variations in formation of the femoral nerve in 12(35%) of the investigated lumbar plexuses in a descriptive cadaveric anatomical study. In these plexuses, it was observed that the femoral nerve bifurcated into 2 or 3 separate slips by the fibres of the psoas major muscle before rejoining proximal to the inguinal ligament. One cadaver had a medial and lateral bifurcation with the substance of the psoas major muscle between with an intermediate connection within the psoas substance and a more distal rejoinder. In the distal course of the nerve, one cadaver (2%) demonstrated a single anterior cutaneous branch instead of the typical two (medial and intermediate) anterior cutaneous branches.

A similar cadaveric study by Spratt, Logan and Abrahams(1996)demonstrated a variant slip of the iliacus and psoas muscles that split the femoral nerve just proximal to the inguinal ligament. This accessory slip of the iliacus arose from the iliolumbar ligament and extended to traverse the femoral nerve and attached to the lesser trochanter. In another study, Woodworth, Lee, Beckett and Ivie (2013) noted the nerve embedded partially within the iliacus muscle within the femoral triangle in 2.29%(95% CI) of cases studied.

An Asian study by Astik and Dave (2011)demonstrated early divisions of the nerve in 2 cadavers, 38mm and 40 mm proximal to the inguinal ligament into the anterior and posterior divisions. In another study, Das and Vasudeva, (2007) demonstrated an anomalous higher division of the femoral nerve 3.2 cm proximal to the inguinal ligament into its anterior and posterior branches in a male cadaver. In other studies, the lateral femoral cutaneous nerve has been demonstrated to arise directly from the femoral nerve proximal to the inguinal ligament in 6(10%) of cases(Sim and Webb, 2004) and distal to the mid-inguinal point(Dias Filho et al., 2003).

The intra and extrapelvic course of the femoral nerve places it at risk of various non-iatrogenic (Vázquez, Murillo, Maranillo, Parkin, and Sanudo, 2007) and iatrogenic insults secondary to its intimate relationship with the pelvis, hip joint and proximal femur(Chelly, Uskova, and Plakseychuk, 2010). Furthermore, hip and pelvic operations are some of the most common orthopaedic procedures(Anyanwu, Ekezie, Obikili, and Onyemaechi, 2014).

1.2 Problem statement

The femoral nerve function plays an important ambulatory role primarily in the stance phase of gait (Burke, Walsh, O'Brien, and Synnott, 2010). The documented ethnic and demographic variations in course and branching pattern(Watson et al., 2014) and its intimate relationship with the pelvis, hip joint and proximal femur places it at risk of injury through dislocations, fractures, direct blows or surgery. Femoral neuropathy results in ipsilateral hip flexion and knee extension deficits and hypoesthesia impairment on the anteromedial aspect of the thigh(Bono, la Bella, and Spataro, 2015) and patella areflexia. Injury is associated with high patient morbidity with impairment in basic daily functions including walking, climbing up and down stairs. There has been a gradual increase in cases of femoral neuropathy following hip arthroplasty (Al-Ajmi, Rousseff, and Khuraibet, 2010). The increasing number of non-iatrogenic and iatrogenic femoral nerve insults, the documented ethnic variations, and the unknown course of the femoral nerve among the Kenyan population demonstrate the need for an anatomic description of the nerve among our population.

1.3 Justification

Femoral neuropathy has received little attention in general surgery and orthopaedic related pelvic surgeries with most authors attributing it to errant retractor placement(Celebrezze, Pidala, Porter, and Slezak, 2000). This study aims at dissecting, charting the length and course of the femoral nerve and its main branches and documenting any variations. Findings could be applied in validating previously described femoral nerve anatomy applicable in preoperative and intraoperative planning. Findings from this study will provide a precise anatomical guide to orthopaedic and non-orthopaedic surgeons in various pelvic and pelvic-femoral surgeries(Bono et al., 2015). Morphometric findings from this study could act as a foundation for subsequent related studies. Precise anatomical knowledge of the femoral nerve will minimise direct transection, electrocautery or suture placement associated femoral nerve insults.

In this setup with constrained resources and the absence of technological advancements (such as nerve conduction studies), a clear anatomical description of the femoral nerve will reduce surgical complications.

1.4 Research Question

What is the anatomical course and length of the femoral nerve (s) (and its main branches within the femoral triangle) in relation to the inguinal ligament (proximal and distal to the inguinal ligament) in the adult Kenyan population?

1.5 Research Objectives

1.5.1 Broad Objective

To describe the anatomical course and length of the femoral nerve(s) (and its main branches within the femoral triangle) in relation to the inguinal ligament (proximal and distal to the inguinal ligament) in the adult Kenyan population.

1.5.2 Specific Objectives

1. To determine the length of the femoral nerve (proximal and distal to the inguinal ligament) and its main muscular branches within the femoral triangle in the Kenyan adult population.
2. To describe the pattern of distribution of both the anterior and posterior muscular branches of the femoral nerve within the anterior compartment of the thigh in the Kenyan adult population.

CHAPTER TWO: LITERATURE REVIEW

2.1 Overview

2.1.1Surgical anatomy

The femoral nerve is covered by the thick and less distensible iliacus fascia as it approaches the inguinal ligament which has been postulated to be a cause of nerve compression(Chin, Hsieh, and Wang, 2007; Swami et al., 2020) and subsequent ischemia. It descends beneath the inguinal ligament to emerge in the femoral triangle in a groove between the iliacus and psoas muscles at the midpoint of the inguinal ligament where its course is directly above the capsule of the hip joint separated by the iliopsoas tendon (Standring and Gray, 2008). The femoral nerve divides 2-3cm (1-1.5in) below the inguinal ligament into the anterior and posterior branches separated by the lateral circumflex femoral artery. The anterior branch has motor (pectineus and sartorius muscles) and sensory (intermediate and medial cutaneous femoral nerves) branches. The posterior branch has motor(quadriceps femoris) and sensory(saphenous nerve) branches(Cunningham and Romanes, 1995).

Blood supply to the femoral nerve within the pelvis is from the iliolumbar artery while deep circumflex iliac and lateral circumflex femoral arteries perfuse the nerve outside the pelvis. A more generous blood supply on the right has been postulated as a reason for more reported cases of left femoral neuropathies secondary to an ischemic insult (Celebrezze et al., 2000).

The intrapelvic proximal segment innervates one of the main hip flexors (iliacus) through short branches from the posterior aspect of the nerve. The extrapelvic portions through its main branches have motor, sensory and articular branches. Motor branches ensure hip flexion by the iliopsoas complex and knee extension by the rectus femoris and the vasti: medialis, intermedius and lateralis. Sensory innervation is to the anterior and medial aspect of the thigh as well as the medial aspect of the knee, leg and the instep of the foot (Standring and Gray, 2008).

The intra and extrapelvic course of the femoral nerve places it at risk of various traumatic and non-traumatic insults secondary to its intimate relationship with the pelvis, hip joint and proximal femur(Chelly et al., 2010).

2.1.2 Iatrogenic and non-iatrogenic femoral nerve insults

A systematic review study by Chelly et al., published in 2009 with articles spanning from 1943 to 2008 demonstrated that the incidence of nerve palsy was 0.3% to 4% in primary Total Hip Arthroplasties (THAs) with 1% as the suggested figure in general orthopaedic experience. Furthermore, nerve conduction studies demonstrated that nerve insults could occur in up to 70% cases. Demonstrated causes included limb lengthening by more than 4cm, haemorrhage, revision arthroplasty, duration of surgery and congenital dislocation. However, the aetiology was unknown in most cases. In this systematic review, the first large series of nerve palsies (50 cases) was reported in 1984 by Retcliff with traction being the most common cause. Similarly, within this systematic review, 37 cases of sciatic and femoral neuropathy were reported in 1992 by Birsch. The precise cause was however unknown in over 50% of cases. They postulated ischemia, traction, compression, direct trauma, intra- and extra-neural bleed and cement burn as the most probable cause (Chelly et al., 2010).

More recently, in 2005, 47 cases of postoperative motor neuropathy were reported. Complete palsies were 29 (2 being femoral), while 18 were incomplete (1 femoral). Developmental dysplasia of the hip (p=0.0004), preoperative post-traumatic arthritis (p=0.01), limb lengthening (p=0.01) and non-cemented femoral component fixation (p=0.03) increased odds of developing motor neuropathy(Farrell, Springer, Haidukewych, and Morrey, 2005).

Iatrogenic intraoperative femoral neuropathy in hemi or total hemiarthroplasty is associated with stretching, compression of the nerve by self-retaining retractors, ischemia and iliopsoas hematoma (Bono et al., 2015). Hypothesized pathophysiological causes include cement encapsulation, compression, ischemic insult, stretching, ligation, transection and iliopsoas hematomas(Chin et al., 2007). Acute nerve stretching up to 6% has been shown to cause permanent damage(Chelly et al., 2010).

Kim and Kline (1995) who carried a 33 year retrospective study of 119 surgically treated thigh and pelvic level femoral nerve injuries demonstrated an iatrogenic aetiology at 58% as the most common cause (52 cases). These were pelvic and hip surgeries.

Another study done over 20 years by Kim, Murovic, Tiel, and Kline (2004) aimed at portraying the surgical outcomes for intra and extrapelvic femoral nerve lesions. Majority (60 %) (n=47) out of the 78 traumatic femoral neuropathies were secondary to operative procedures including 12 patients following hip replacement. Most of these patients had near total motor and sensory loss immediately after the surgery.

Hip hemiarthroplasties have been complicated with compressive femoral neuropathy secondary to post-operative iliacus hematoma or abscess (Andreani, Nucci, Giuntoli, and Lisanti, 2017; Ha, Ahn, Jeong, Park, and Koo, 2001; Nobel, Marks, and Kubik, 1980; Yi, Yoon, Kim, Lee, and Kim, 2012).

A 5-year study conducted in Greece and Switzerland demonstrated 4 cases of femoral paralysis, 3 transient and 1 permanent, following minimally invasive anterior surgery technique. EMG demonstrated axonotmesis(Macheras et al., 2016).

The transpsoas lateral retroperitoneal approach for spinal arthrodesis of disc spaces cephalad to L5-S1 has an 8% -30% rate of iatrogenic femoral neuropathy. Absence of perineurium and epineurium on nerve roots results in higher risk of mechanical neuropathy with trivial forces(Davis et al., 2011).

2.2 Surgical approaches to the pelvis and hip with relation to the femoral nerve

Hip arthroplasties are progressively gaining momentum and have been identified as the most recognised advancement in rheumatoid arthritis and osteoarthrosis in the last two decades. In the United States from 1990 to 2002 the rate of primary THAs increased by 50% per 100,000 people. Furthermore, revision THAs increased by 3.7 cases per 100,000 people per decade (Chelly et al., 2010).

Various surgical approaches based on dissection planes have been described and adopted by individual surgeons. Clinical examination alone has been demonstrated to underestimate post-operative neuropathy following THA(Chelly et al., 2010). Femoral neuropathy has been demonstrated in the lateral approach by electrophysiological studies by Weber, Daube and Coventry (1976) who demonstrated a 70% incidence of neuropathy following a transtronchanteric approach. A good anatomic understanding of the femoral nerve would guide surgeons in avoiding iatrogenic injury(Anyanwu et al., 2014).

The three main approaches described that expose the femoral nerve to highest risk of iatrogenic insult are the anterior, anterolateral, and lateral approaches described below(Chelly et al., 2010).

Table 1: Approaches to the hip that expose the femoral nerve to highest risk of iatrogenic injury

	Anterior	Anterolateral	Lateral
Patient position	Supine	Supine	Lateral
Skin incision	Along anterior half of iliac crest to ASIS, then 10 cm vertically to lateral side of patella	15 cm straight longitudinal incision centered on greater trochanter	10-15 cm incision centered on tip of greater trochanter with hip and leg flexed
Muscles and nerves	Sartorius (femoral) and tensor faciae latae (superior gluteal)	Tensor faciae latae (superior gluteal) and gluteus medius (superior gluteal)	Tensor faciae latae (superior gluteal) and gluteus maximus (inferior gluteal)
Advantages	Low risk of sciatic nerve injury	Possibility of lengthening both legs during surgery	Good exposure of acetabulum, low risk of sciatic nerve injury
Risks and disadvantages	Damage to **femoral nerve**, lateral femoral cutaneous nerve and ascending branch of lateral femoral circumflex artery	Partially cut into tendon of the middle Gluteus muscle. Damage to **femoral nerve** and descending branch of lateral femoral circumflex artery	Damage to superior gluteal nerve and **femoral nerve** and to gluteus medius muscle
Postoperative	Numbness and/or hyperesthesia in latero-femoral cutaneous territory (variable in anterior aspect of thigh)	Longer period of postoperative limp	Decreased rates of hip dislocations. Trouble with limp

ASIS=anterior superior iliac spine.

2.2.1 Anterior approach

This is also referred to as the Smith –Peterson or iliofemoral approach (Anyanwu et al., 2014). This approach preserves the abductor mechanism and offers good exposure of the acetabulum.

Indications include hemi/total hip arthroplasty, pelvic osteotomy, arthrotomy for irrigation or drainage in septic hip arthritis, synovial biopsy and congenital dislocation of the hip. The incision is made from the middle of the iliac crest anteriorly to the ASIS and then distally for 8-10cm on along the line joining the ASIS and the head of the fibula/lateral aspect of patella(Anyanwu et al., 2014).

The mini-incision approach starts 2cm caudal and posterior to the ASIS extending 6-8cm along the line joining the ASIS to the head of the fibula. The superficial and deep fasciae are divided as the attachments of the tensor fascia lata and gluteus medius are released from the iliac crest. 2-3 inches below the ASIS locate the interval between the Sartorius and Tensor fascia lata. The lateral femoral cutaneous nerve that pierces the deep fascia close to this muscular interval should be identified and protected (Anyanwu et al., 2014; Lee et al., 2017).

Retract the Sartorius superomedially while the TFL is retracted inferolaterally. The ascending branch of the lateral circumflex femoral artery that crosses this interval should be identified and ligated (Anyanwu et al., 2014).

Advance the dissection between the rectus femoris (detached and retracted medially) and the gluteus medius (detached and retracted laterally). The capsule of the hip joint is thus exposed(Anyanwu et al., 2014).

Certain anaesthetic techniques targeted at femoral neuraxial anaesthesia have been described in lower limb orthopaedic surgeries including knee arthroplasties, femur, tibial, foot and ankle osteosynthesis, knee arthroscopies including lateral supratochanteric approaches (Albokrinov, Fesenko, Huz, and Perova-Sharonova, 2017; Haddad and Williams, 1995).

2.2.2 Anterolateral approach

This approach exploits the intermuscular plane between the gluteus medius and the tensor fascia latae and affords safe acetabular exposure. It was initially popularised by Watson-Jones in 1936 (Henky, 2007) and later modified by Charnley in 1979 (Charnley and Charnley, 1979). The skin incision is made at a point 2-3cm posterior to the ASIS directed toward the midpoint of the greater trochanter and extended 10-15cm along the longitudinal axis of the femur. It is then advanced into the fascia lata. The incision is extended anterosuperiorly towards the ASIS and anteroinferiorly to expose the vastus lateralis. The interval between the tensor fascia lata and the gluteus medius is dissected bluntly midway between the ASIS and the Greater trochanter. This prevents injury to inferior division of superior gluteal nerve. The gluteus medius and minimus are then retracted proximally and laterally exposing the superior aspect of the joint capsule. Indications include: Total/Hemiarthroplasty, ORIF for femoral neck fractures, synovial biopsy and osteosynthesis of acetabular fractures (Anyanwu et al., 2014).

2.2.3 Lateral Approach

The lateral approaches are further subdivided into direct lateral and transtrochanteric approaches. The mid-lateral skin incision is made over the greater trochanter and advanced into the fascia lata and the iliotibial band. The gluteus maximus is identified and dissected posteriorly while tensor fascia lata is retracted anteriorly. The gluteus medius is then separated from the adjacent musculature by blunt dissection. The tendon of the gluteus medius, the periosteum and vastus lateralis are retracted to expose the gluteus minimus. The tendon of the gluteus minimus is divided and retracted proximally to expose the joint capsule. The transtrochanteric technique involves greater trochanteric osteotomy with the attachments of the gluteus medius(Anyanwu et al., 2014).

2.3 Length of the femoral nerve and its main muscular branches

The femoral nerve is anatomically considered as the largest branch of the lumbar plexus arising from the posterior divisions of the ventral rami of L2 – L4 nerve roots(Cunningham and Romanes, 1995; Standring and Gray, 2008). Its main trunk has been documented to emerge 4-6cm above the inguinal ligament on the anterolateral part of the psoas muscle, inferiorly(Davis et al., 2011; Oyedun et al., 2014).

Passing behind the inguinal ligament at the midpoint of the inguinal ligament, the femoral nerve divides 2-3cm (1-1.5in) below the inguinal ligament into the anterior and posterior branches separated by the lateral circumflex femoral artery within the femoral triangle(Cunningham and Romanes, 1995; Standring and Gray, 2008). Gustafson et al., (2009) described the nerve branching off at 15.0 mm distal to the level of the inguinal ligament Vloka et al., 1999 in a New York based cadaveric study involving 9 specimens described the nerve branching within 2.5cm distal to the inguinal ligament and its importance in appropriate estimation for femoral nerve regional anesthesia block necessary for orthopedic procedures. However, the actual lengths of the main muscular branches of the femoral nerve could not be found in the standard anatomy textbooks used during this literature review.

2.4 Patterns of distribution of the anterior and posterior muscular branches

The nerve, as described in standard anatomy textbooks, traverses beneath the inguinal ligament to emerge within the femoral triangle lying lateral to the femoral sheath. The anterior branch has motor (pectineus and sartorius muscles) and sensory (intermediate and medial cutaneous femoral nerves) branches. The posterior branch has motor (quadriceps femoris) and sensory (saphenous nerve) branches. Branches to the iliacus and pectineus muscles arise while still in the abdomen as well as a small vascular branch to the proximal part of the femoral artery(Standring and Gray, 2008).

Additionally, the nerve to pectineus branches from the medial side of the femoral nerve near the inguinal ligament. It then passes behind/posterior to the femoral sheath before entering the anterior aspect of the muscle. The main nerve to sartorius arises from the femoral nerve in common with the intermediate cutaneous nerve of the thigh. Boo-Chai, (1984) and Yu et al., (2010) described the nerve deep to the Sartorius muscle with sub-branches to the muscle. The lateral branch of the intermediate cutaneous nerve communicates with the femoral branch of the genitofemoral nerve, frequently piercing sartorius and sometimes supplying it(Standring and Gray, 2008).

The muscular branches of the posterior division of the femoral nerve innervate the *quadriceps femoris*. The branch to *rectus femoris* enters the muscle from its deep/posterior surface proximally(Sung, Jung, Kim, Ha, and Ko, 2003; Yang and Morris, 1999). The branch to *vastus lateralis* is larger and forms a neurovascular bundle with the descending branch of the lateral circumflex femoral artery in its distal part and also supplies the knee joint. The branch to *vastus medialis* descends into the adductor canal proximally, laterals to the saphenous nerve and femoral vessels, and enters the muscle at about its midpoint (Nozic, Mitchell, and De Klerk, 1997; Rajput, Rajani, and Vaniya, 2017; Thiranagama, 1990). This branch also sends a long articular twig distally along the muscle to the knee. The vastus intermedius muscle receives two or three branches on its anterior surface about the mid- thigh(Sung et al., 2003; Thiranagama, 1990). A small branch from one of these descends through the muscle to innervate the articularis genu and the knee joint(Cunningham and Romanes, 1995; Standring and Gray, 2008).

2.5 Variations

Variations of the femoral nerve have been documented from its formation to its course within the psoas muscle to its union proximal to the inguinal ligament (Astik and Dave, 2011). However, there is paucity of studies that describe variations within the femoral triangle.

Ethnic variations in the branching pattern of the femoral nerve have been described in literature. Watson et al., (2014) identified anatomical variations of the femoral nerve in relation to the bony landmarks of the inguinal ligament between different ethnic and demographic populations. At the level of superior aspect of the greater trochanter, the mean distance from the ASIS to the femoral nerve was 23.24mm (3.4-67.0mm). However, the femoral nerve vector varied between Caucasians and African Americans (p=0.04) as well as among Hispanics and African Americans (p=0.04).

Anloague and Huijbregts (2009) demonstrated variations in formation of the femoral nerve in 12(35%) of the investigated lumbar plexuses in a descriptive cadaveric anatomical study. In these plexuses, it was observed that the femoral nerve bifurcated into 2 or 3 separate slips by the fibres of the psoas major muscle before re-joining proximal to the inguinal ligament. One cadaver had a medial and lateral bifurcation with the substance of the psoas major muscle between with an intermediate connection within the psoas substance and a more distal rejoinder. In the distal course of the nerve, one cadaver (2%) demonstrated a single anterior cutaneous branch instead of the typical two (medial and intermediate) anterior cutaneous branches.

A cadaveric study by Spratt et al., (1996) demonstrated a variant slip of the iliacus and psoas muscles that split the femoral nerve just proximal to the inguinal ligament. This accessory slip of the iliacus arose from the iliolumbar ligament and extended to traverse the femoral nerve and attached to the lesser trochanter.

An Asian study by Astik and Dave (2011)showed that 25%(n=16) dissected lumbar plexuses had variations in formation and branching and relations to the iliopsoas complex. One of the cadavers had an L2 root spanning 92 mm with the femoral nerve spanning 42mm proximal to the inguinal ligament. 2 cadavers had early divisions of the nerve 38mm and 40 mm proximal to the inguinal ligament into the anterior and posterior divisions. Femoral nerve was split into 2 slips in 3 lumbar plexuses by the psoas major muscle but re-joined 45mm above the inguinal ligament in 2 specimens and 40mm above the inguinal ligament in 1 plexus.

Das and Vasudeva (2007) demonstrated an anomalous higher division of the femoral nerve 3.2 cm proximal to the inguinal ligament into its anterior and posterior branches in a male cadaver. Astik and Dave (2011) also showed higher branching of the femoral nerve at variable distances above the mid-inguinal point in two specimens. In other studies, the lateral femoral cutaneous nerve has been demonstrated to arise directly from the femoral nerve proximal to the inguinal ligament in 6(10%) of cases (Sim and Webb, 2004) and distal to the mid-inguinal point(Dias Filho et al., 2003).

A more recent cadaveric study done in Kamal, India demonstrated the nerve to have been split into two divisions above the inguinal ligament by two slips of the Iliacus muscle. This was demonstrated on the left side in 50-60 year old female cadaver. The two slips reunited proximal to the inguinal ligament forming the femoral nerve trunk without mention of the actual length with relation to the inguinal ligament (Swami et al., 2020)

The motor branch of the rectus femoris was noted by Sung et al.,(2003)to branch out about 2 fingerbreadths below the inguinal ligament from the femoral nerve trunk and ran downwards and slightly laterally. Before reaching the medial border of the rectus femoris muscle, it divided into 2 smaller sub-branches. The superior sub-branch was noted to run laterally deep to the posterior surface of this muscle before entering it at the proximal third of this muscle with a vascular pedicle. Additionally, the inferior sub-branch pierced the muscle fascia at its medial border with another vascular pedicle. It then descended along the medial border of the muscle. It was however noted that there were no gender differences in the cadavers dissected.

The study went further to demonstrate that the motor branch of the vastus medialis with the saphenous nerve divided from the femoral nerve trunk just distal to the inguinal ligament. This motor branch descended medially alongside the femoral artery. The motor branches of the vastus lateralis and intermedius branched from the femoral nerve trunk 1 to 2cm distal to the dividing point of the motor branch of the rectus femoris. The motor branch of the vastus intermedius descended deep to the muscle. The motor branch to the vastus lateralis divided into 2 subbranches in 21 extremities and into 3 subbranches in 1 extremity. The subbranches descended initially between the rectus femoris (above) and the vastus intermedius (below). These sub-branches entered the interval between the vastus intermedius and vastus lateralis before penetrating the medial surface of the vastus lateralis at its proximal and distal third, respectively(Sung et al., 2003).

CHAPTER THREE: METHODOLOGY

3.1 Study site

The study was conducted at the Human Anatomy Laboratory, Moi University School of Medicine. This is situated at Moi Teaching and Referral Hospital, Eldoret, about 310km northwest of Nairobi, the capital city of Kenya.

3.2 Study design

The study was an anatomical descriptive cross sectional design involving relations of the femoral nerve to the bony landmarks of the inguinal ligament and distribution of the femoral nerve in cadaveric specimens at the Human Anatomy Department, Moi University.

3.3 Study population

This included sequentially selected adult Kenyan formalin prefixed cadaveric pelvic and lower limb specimens from the Department of Human Anatomy, Moi University School of Medicine. Majority of the limbs available at the department were disarticulated along the Hemipelvectomy planes. This plane extends along the pubic symphysis and the ipsilateral sacroiliac joint with preservation of the ipsilateral pelvic bones. This preserved the bony attachments of the inguinal ligament as well as the distal portions of the psoas major and iliacus muscles. Thus, the proximal portion of the femoral nerve as it emerges at the anterolateral distal portion of the psoas major was followed to the level of the inguinal ligament. Sex of the cadavers was recorded in the data collection sheet.

3.4 Eligibility Criteria

3.4.1 Inclusion criteria

All adult pelvic and lower limb cadavers without gross evidence of fracture, pathology or prior surgery were included.

3.4.2 Exclusion criteria

Deformed or mutilated cadavers were excluded from the study.

3.5 Sampling and Sample size determination

The maximum number of affixed unilateral pelvic and lower limb cadaveric specimens attainable at the Moi University Human Anatomy Laboratory meeting the inclusion criteria totalled 56 specimens.

3.6 Data Collecting Materials/Tools and Methods/Techniques

3.6.1Data Collecting Materials/Tools

The cadavers were dissected, and the parameters mentioned in the objectives were measured using a Vernier calliper accurate to 0.01mm. Length measurements of nerves were measured using a string placed along the required length, accurately marked with a pointed permanent marker pen. The string was then straightened and the marked length along the string was then transferred and measured using the calibrated calliper. Data was captured in structured data collection forms. The innervations patterns of the main branches (anterior and posterior) were also photographed using a digital camera (Sony® DSC-W180 10.1 megapixels).

3.6.2 Data Collection Technique/Method

Dissections were done according to the techniques described by The Cunningham's Manual of Practical Anatomy 16th Edition(Koshi, 2017). Dissections begin at the base of the femoral triangle and then major cutaneous and muscular branches were followed into their points of innervations and their course described. The course of the femoral nerve was also dissected bluntly proximal to the femoral triangle to the inferolateral border of the psoas muscle.

Dissection of the femoral triangle involved identifying and exposing the sartorius and adductor longus at the apex of the triangle. A block was positioned under the knee to achieve approximately 15-20° flexion of the ipsilateral hip to relax structures within the triangle. Ipsilateral knee flexion prevented stretching of the femoral nerve and documentation of more accurate measurements. The femoral nerve was identified as it traversed beneath the inguinal ligament and ran lateral to the femoral sheath in the groove between psoas and iliacus muscles. The capsule of the hip joint with the femoral head and femoral neck lay just beneath the iliopsoas muscles at that point. The course of the femoral nerve was followed until its division distal to the inguinal ligament and the major branches were followed to their points of innervations.

Muscular branches of the femoral nerve were identified, and their course described by dissection of the anterior compartment of the thigh. The Sartorius was identified and exposed down to its insertion on the tibia. A vertical incision was then made through the facia lata from the tubercle of the iliac crest to patella’s lateral margin. The fascia lata between this incision and the Sartorius was resected exposing the quadriceps femoris while preserving the iliotibial tract.

The distance of the femoral nerve at the level of the inguinal ligament from the anterior superior iliac spine was measured and labelled as AFN. Similarly, the distance of the femoral nerve at the level of the inguinal ligament from the pubic symphysis was measured and labelled as PFN. The length of the femoral nerve proximal to the inguinal ligament as it emerged on the anterolateral aspect of the psoas major was measured and labelled as FN1. The length of the femoral nerve just distal to the inguinal ligament to its point of division into the main branches (anterior and posterior) was measured within the femoral triangle and labelled as FN2.The points of innervations of the muscular branches was also recorded within the femoral triangle and labelled in relation to the muscle to which it innervated.

The measurements obtained were subjected to statistical analysis to determine any statistically significant differences in nerve distribution between both sexes. However, from available literature, no sexual differences have been observed in the formation and distribution of the femoral nerve among populations studied (Astik and Dave, 2011; Galtier et al., 1995; Sung et al., 2003).

3.7 Data analysis, management, and presentation

Data collected was analysed using IBM SPSS Statistics Version 20.0.0. Measurements obtained were analysed using descriptive methods using IBM SPSS Statistics Version 20.0.0. Variables which were categorical in nature including sex were summarised as frequencies with their percentages. Continuous variables (including pre-inguinal and post-inguinal ligament femoral nerve length and distance from the ASIS and Pubic tubercle) were summarised as mean with their corresponding standard deviation as long as they followed the normal (Gaussian) distribution. Gaussian assumptions were assessed using Shapiro-Wilk normality test. Continuous variables that violated Gaussian assumptions were summarised using median and their corresponding interquartile ranges. Both measures of central tendency and measures of dispersion were utilised as appropriately needed for analysis of continuous variables.

If normal distribution assumptions were satisfied, 2 sample ***t***- tests were used for comparison of continuous variables. Conversely, non-parametric measures were employed as required.

Data collected was coded appropriately using the data collection forms. Computer memory drives (portable and fixed) and compact storage disks were used to store the data for future retrieval. Photographs of dissected specimens were recorded using a digital camera. Finally, the data obtained was presented in form of tables, charts and figures.

Data recorded on the data collection forms was entered into an electronic database encrypted with password to ensure confidentiality. Identifiers such as noted distinct tattoos or skin markings were avoided to breach confidentiality. The password was accessible to the main investigator only. Data forms once converted into the electronic data base were disposed by shredding, after completion of the study.

The ***t***- test was used to compare means and a ***p***- value of ≤ 0.05 was considered statistically significant.

3.8 Ethical considerations

Prior to commencement of the study, ethical approval was sought from the Department of Human anatomy and the Institution Research and Ethics Committee (IREC) Moi University. The Anatomy Act Chapter 243-9 (REVISED EDITION OF 2012) of The Laws of Kenya (National Council for Law Reporting, 2012)was strictly adhered to. This act states and entitles a person registered as a student in an approved school of anatomy to examine and conduct anatomical research on human cadavers as long as the requirements stipulated in the act are strictly adhered to. Data confidentiality was strictly maintained and this included use of passwords in the database.

Results obtained were disseminated through an oral defence of thesis and thereafter the results may be presented at relevant conferences/seminars and publication in a peer reviewed scientific journal.

3.9 Scope and Limitations

1. The availability of cadaveric specimens limited the sample size. This was mitigated by ensuring all available cadavers meeting the inclusion criteria in the anatomy laboratory were studied.
2. The precise anatomical position of the femoral nerve could be displaced during dissection. This will be minimised by ensuring blunt and meticulous dissection as described by anatomic research guidelines(Sa, Z., K, Y. E., Tania, and Ky, 2016).

CHAPTER FOUR: RESULTS

4.1 Bio-demographics

A census study of 56 eligible specimens was studied. Among the dissected specimen 35 (62.50%) were limbs from female cadavers. Majority, 32 (57.14%), constituted limbs from the right side of the body, while the remainder were obtained from the left side. Among female specimen fourteen (66.67%) were obtained from the right side of the body while in males eighteen (51.43%) were obtained from the ipsilateral side. The demographic characteristics of the subjects included in the study are shown in Table 2 below.

Table 2: Bio- demographics

Variable	**Total (n)**	**95% Confident Interval**
Total specimen	56	100%
lSex of the Limb		
Female	21	37.50(24.92-51.45)
Male	35	62.50(48.55-75.08)
Side of the Limb		
Left	24	42.86(29.71-56.78)
Right	32	57.14(43.22-70.29)
Female specimen		
Left	7	33.33(14.59-56.97))
Right	14	66.67(43.03-85.41)
Male specimen		
Left	17	48.57(31.38-66.01)
Right	18	51.43(33.99-68.62)

4.2 Length of the femoral Nerve and its Muscular branches

Measurements of the femoral nerve and the relation of the nerve with the bony pelvis landmarks and the level of the inguinal ligament were conducted. The first (FN1) of such was the measurement of the nerve proximal to the inguinal ligament but distal to anterolateral border of the psoas muscle. Of the dissected specimens the FN1 had a mean of 47.85mm (SD 13.72).The minimum measurement observed was 13.50mm; the maximum was 89.10mm while the median was 45.78 mm (IQR 13.68) and mode was 49.10mm.

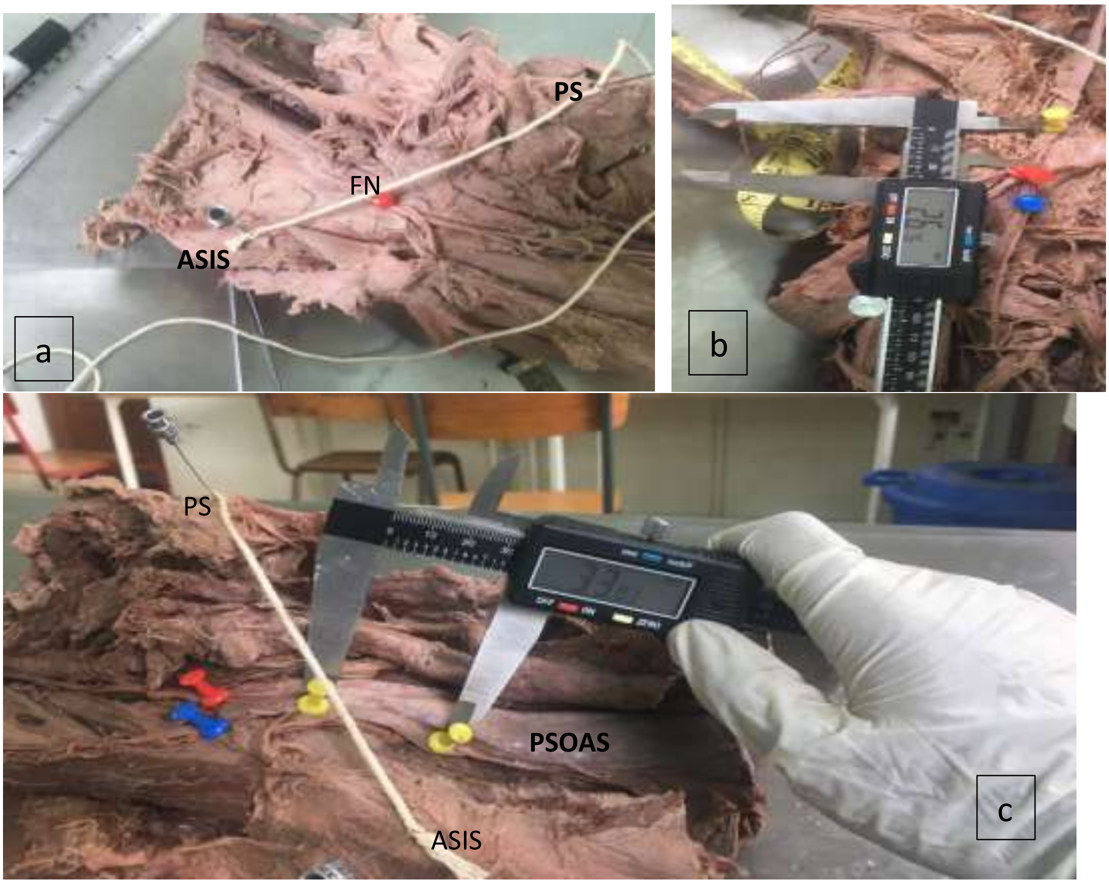

Figure1: Measurements and landmarks. (a) Pins positioned at ASIS and midpoint of pubic symphysis (PS) with thread to denote level of inguinal ligament. Red thumb pin – position of the femoral nerve. (b) Measurement of FN2 from level of inguinal ligament to point of branching. Yellow pin-femoral nerve at inguinal ligament level; red pin--branching point; blue pin--posterior division (c) (FN1) measurement of femoral nerve from iliopsoas proximal to inguinal ligament. Yellow pin—femoral nerve; red pin—posterior division; blue pin—anterior division. .

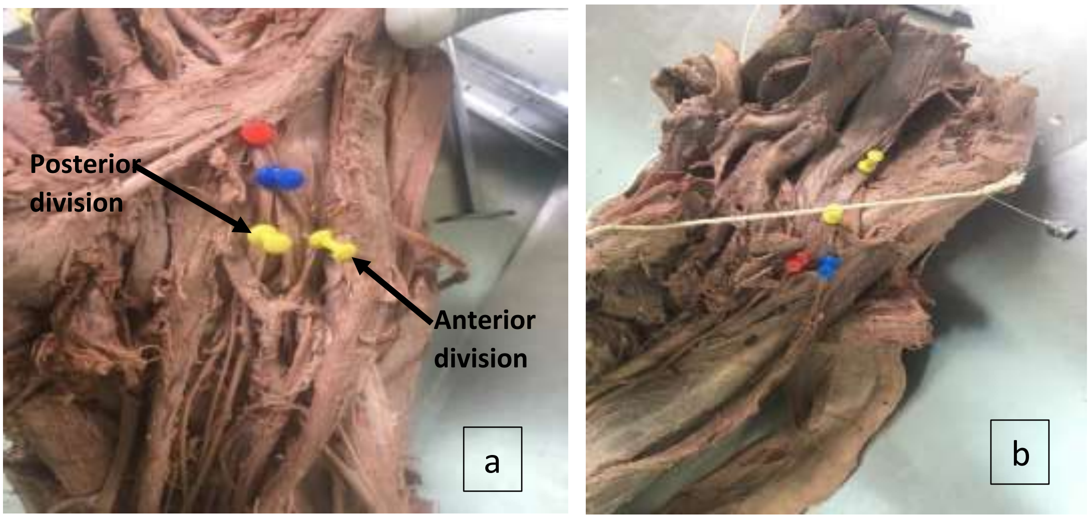

Figure 1: Observed normal described branching pattern of the femoral nerve distal to inguinal ligament into anterior and posterior divisions.(a) red pin—femoral nerve at level of inguinal ligament; blue pin—point of branching into anterior and posterior divisions (yellow pins) (b)yellow pin—femoral nerve; blue pins—anterior division; red pin--posterior division.

The length of the femoral nerve distal to the inguinal ligament to the point of branching into anterior and posterior branches was also ascertained (FN2). For the fifty six specimens, a mean of 29.32 mm (SD 14.239) was obtained. The median was 31.02 (IQR 13.69) and mode was 31.87.

The third measurement (AFN) was done at the level of the inguinal ligament from the anterior-superior iliac spine of the ipsilateral side to the femoral nerve. AFN had a mean of 53.02 mm (SD 14.59), mode of 49.10 mm and median of 54.75 mm (IQR 12.12). The last measurement was from the *symphysis pubis* to femoral nerve at the level of the inguinal ligament (PFN). During this, an average of 72.87mm (SD 19.75).The median was 76.49mm (IQR 15.59) and mode was 85.00.

4.3 Branching patterns of the femoral nerve

We also looked at the branching patterns of the femoral nerve whose summary statistics is shown in table 2 below. In most of the specimens, no anatomical variation was observed 47(83.93%) (71.67-92.38) with the nerve branching into anterior and posterior divisions distal to the inguinal ligament (Figure 3 below).

Figure 2: Normal branching pattern of the femoral nerve distal to the inguinal ligament. Green pin--position of femoral nerve at the inguinal ligament level. Blue pin—anterior division; yellow pin—posterior division.

4.4 Patterns of distribution of the anterior and posterior muscular branches

The anterior branch to *Sartorius* was one of the branches of the femoral nerve that was dissected. The majority, 43(76.79%) (CI 63.58-87.02), of the specimens demonstrated a single branch arising proximally and coursing deep to the muscle, while 4 specimens (7.14%) (CI 1.98-17.29) demonstrated three deep branches to the muscle (Figure 4). Only one of the dissected specimens had the nerve accidentally resected, the remainder, 8(14.29%) (CI 6.38-26.22), had two deep branches to the muscle.

Figure 3: Three anterior femoral nerves slips innervating deep to the Sartorius

Innervation to the *rectus femoris* from the posterior branch was mostly through a single branch deep to the muscle, 27(48.21%) (CI 34.66-61.97), or along the medial border, 26(46.43%) (CI 33.99-60.26)(Figure 5).

Figure 4: Two muscular nerve slips to the medial border of the rectus femoris.

Table 3: Branching patterns of the femoral Nerve

Variable	**Total (n)**	**95% Confidence Interval**
Anterior Branch To Sartorius		
Deep 3 branches	4	7.14(1.98-17.29)
Deep to Sartorius one Branch	43	76.79(63.58-87.02)
Deep with 2 branches	8	14.29(6.38-26.22)
Resected	1	1.79(10.05-9.55)
Posterior Branch To *rectus femoris*		
Along medial border	26	46.43(33.99- 60.26)
Deep to muscle single branch	27	48.21(34.66-61.97)
Deep arising before reaching the Inguinal Ligament.	2	3.57(0.44-12.31)
Missing/Not seen	1	1.79(0.05-9.55)
Posterior Br. To *vastus Lateralis*		
Along the Medial border	54	96.43(87.69-99.56)
Four branches to medial border	1	1.79(0.05-9.55)
Two deep branches to medial border	1	1.79(0.05-9.55)
Posterior Br. To *Vastus Intermedius*		
Along Medial border	44	78.57(65.56-88.41))
Superficial perforates Muscle	12	21.43(11.59- 34.44)
Posterior Br. To *Vastus medialis*		
In the adductor canal	55	98.21(90.45-99.95)
Three Br. To V. *Medialis*	1	1.79(0.05-9.55)
Observed anatomical Variations		
None	47	83.93(71.67-92.38)
Branching at Inguinal Ligament	6	10.71(4.03-21.88)
Branching proximal to Inguinal Ligament	2	3.57(0.44-12.31)
Slip from Psoas dividing nerve trunk into two uniting proximal to Inguinal Ligament	1	1.79(0.05-9.55)

Consideration was made for the innervations of the remaining three *vasti* muscle of the quadriceps *femoris* group. Upon investigation of the Innervation patterns for the *Vatus lateralis* muscle, almost all, 54 (96.43%) (CI 87.69-99.56) revealed an innervation of a single branch along the medial border of the muscle (Figure 6).

Figure 5: Commonest innervation pattern to the vastus lateralis with one nerve slip along the medial border

There were only two exceptions to this pattern, one with four branches to the medial border of the muscle (Figure 7) and another with two branches to the medial border each representing 1.79% (CI 0.05-9.55).

Figure 6: Four muscular nerve slips along the medial border of the vastus lateralis.

Innervation of the *Vastus Intermedius* was also elucidated. The majority of the dissected specimens had innervation of this muscle along the medial border 44(78.57%) (CI 65.56-88.41), the remainder being superficial nerves perforating the muscle 12(21.43%) (CI 11.59-34.44).Upon examination of the nerves to the *vastus medialis* all but one had a single branch arising within the adductor canal 55(98.21%) (CI 90.45-99.95), the exception being a finding of three branches to the muscle with one of the branches arising slightly proximal within the femoral triangle (Figure 8).

Figure 7: Three muscular slips along the medial border of the vastus medialis

4.5 Observed anatomical branching pattern variations.

Any anatomical variation in the femoral nerve was also noted for each record. Majority, 47(83.93%) (71.67-92.38), of the cadaveric limbs had no observed anatomical variations observed. However, 6 cadaveric specimens, (10.71%) (4.03-21.88), demonstrated the nerve branching at the level of the inguinal ligament. A further 2(3.57%) (0.44-12.31) had a more proximal branching above the level of the inguinal ligament (Figure 9). One cadaveric limb had the femoral nerve branching 30.44mm while the other 27.39mm proximal to the level of the inguinal ligament.

Figure 8: (a) Femoral nerve branching proximal to the inguinal ligament, (b) Femoral nerve branching at the level of the inguinal ligament.

One studied specimen had a more variant anatomy with a slip from the psoas muscle dividing the nerve trunk into two divisions that were uniting 25.88mm proximal to the inguinal ligament (Figure 10).

Figure 9: Psoas muscle slip dividing the nerve trunk into 2 slips (blue pins) that united 25.88mm proximal to the inguinal ligament forming the main nerve trunk (yellow pin) that divided distally from the level of the inguinal ligament into anterior (green) and posterior (red) divisions

4.6 Gender- stratified Sub analysis

Stratified analysis for each of the sex of the limbs was conducted to ascertain existence of any gender differences.

4.6.1 Limbs from Female specimen.

The female specimen constituted twenty-one in number. Upon consideration of the female specimen only, majority of the specimen 14(66.67%) were from the right side of the body. The mean length of the femoral nerve proximal to the level of the inguinal ligament was 49.04 mm (SD 12.64), median 49.10 (IQR 8.34) and Mode 49.10mm.When we measured the nerve distal to inguinal ligament, the mean was 31.36(SD 14.45) and median 30.25mm (IQR 19.40) and mode of 30.36.The measurement from ASIS to inguinal ligament gave an average length of 47.74mm(

SD 20.91), Median of 51.10mm (IQR 13.17) and mode of 49.61 mm. Measurement of the interception of the femoral nerve at the level of the inguinal ligament and the ipsilateral symphysis pubis revealed a mean of 69.29mm (SD 29.25), median of 79.01 mm (IQR 10.77) and a mode of78.43 mm.

4.6.2 Limbs from Male specimen

The majority of the cadaveric limbs studied were male totalling 35, with eighteen (51.43%) being from the right side of the body and the remainder from the left. The nerve proximal to the level of the inguinal ligament measured an average of 47.13 mm (SD 14.46), median of 45.00mm (IQR 15.82) and mode of 13.50mm. The nerve trunk distal to the level of the inguinal ligament measured an average of 28.09mm (SD 14.17), median of 31.32 mm (IQR 10.11) and mode of 3.77mm. Upon measurement of the nerve interception with the level of the inguinal ligament to the ASIS, the length measured 56.19 mm in average, median being 56.10 mm (IQR 9.79) and mode 49.10 mm. Lastly, consideration was made for the length between the symphysis pubis and the interception of the nerve at the inguinal ligament. The mean length was established to be 75.02mm (SD 10.74) median was 73.90 mm (IQR 13.88).

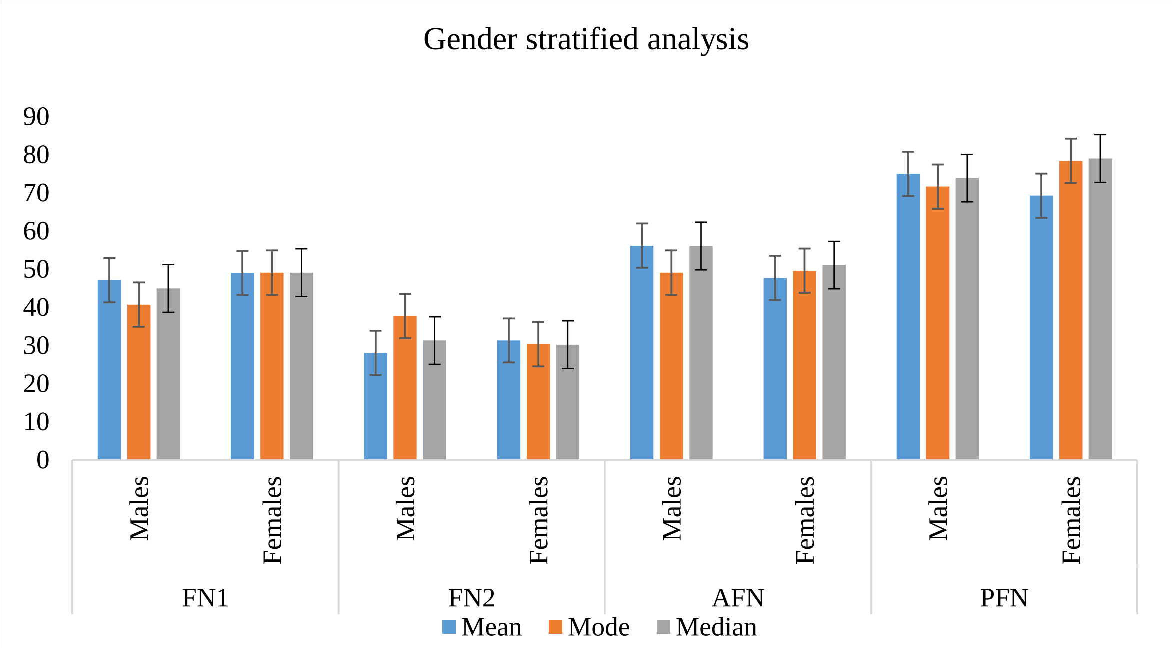

Figure 10: Gender stratified sub-analysis.

Table 4: Gender stratified sub-analysis for statistical significance

	Test	Test Value	Cut off	***p***- Value
FN1	Pooled ***t***- Test	0.5	0.6192	
	ANOVA	0.24991		0.6192
	Mann Whitney	0.4029		0.5256
FN2	Pooled ***t***- Test	0.33	0.4109	
	ANOVA	0.68667		0.411
	Mann Whitney	0.6608		0.4163
AFN	Pooled ***t***- Test	-2.17	0.0346	
	ANOVA	4.7003		0.3046
	Mann Whitney	1.2291		0.2676
PFN	Pooled ***t***- Test	-1.04	0.2968	
	ANOVA	1.1097		0.2968
	Mann Whitney	0.6195		0.4312

The comparative sub analysis of individual measurements demonstrated variability in lengths between genders but the ***p***- values >0.05 demonstrated no statistical significance in variance. This demonstrates no significant gender differences as shown in literature.

CHAPTER FIVE: DISCUSSION

Descriptions of iatrogenic insults and position of the femoral nerve in relation to the proximal femur have been documented(Chelly et al., 2010; Vázquez et al., 2007). Some studies have demonstrated position of the femoral nerve with various subtypes of femur neck fractures and possibility of iatrogenic insults(Haddad and Williams, 1995). Cadaveric studies have further demonstrated variant course and branching of the femoral nerve even with reference to the individual nerve roots precedent to and after the formation of the nerve (Anloague and Huijbregts, 2009; Astik and Dave, 2011; J. D. Spratt et al., 1996; Swami et al., 2020). This variability should be considered in individuals presenting with idiopathic atraumatic/traumatic motor or sensory deficits along the femoral nerve innervation dermo-myotome path. Femoral nerve blocks are also useful in providing anaesthesia and postoperative analgesia for non-hip fracture surgery and extracapsular neck of femur fractures (Haddad and Williams, 1995).

5.1 Length of the femoral Nerve and its Muscular branches

Measurements of the femoral nerve and the relation of the nerve with the bony pelvis landmarks and the level of the inguinal ligament were conducted. The first of such was the measurement of the nerve proximal to the inguinal ligament but distal to anterolateral border of the psoas muscle. In this study the mean length of the nerve was 47.85mm (SD 13.719), concurs with documented findings(Davis et al., 2011; Oyedun et al., 2014). However, there is paucity of studies with reference to any ethnic/racial variability and with regard to the muscle bulk of the psoas muscle or in relation to actual length of the individual nerve roots. This therefore demonstrates that the nerve underlies the fascia iliaca for around 5cm proximal to the inguinal ligament which should be considered in patients presenting with hip/knee arthralgia as a consequence of iliacus hematoma or abscess(Andreani, et al., 2017; Ha, Ahn, Jeong, Park, and Koo, 2001; Nobel, Marks, and Kubik, 1980; Yi, Yoon, Kim, Lee, and Kim, 2012).

The mean length of the femoral nerve distal to the inguinal ligament to the point of branching into anterior and posterior branches was 29.32 mm (SD 14.239). This was slightly higher than that described on average by Gustafson et al., (2009) at 15.0 mm which would propose a slightly more distal branching point in our population. Vloka et al., 1999 in a New York based cadaveric study involving 9 specimens described the nerve branching within 2.5cm distal to the inguinal ligament and its importance in appropriate estimation for femoral nerve regional anesthesia block necessary for orthopedic procedures. This figure still fell slightly short of our mean finding suggesting a longer nerve length distal to the inguinal ligament in Kenyan population.

The femoral nerve mean length was 53.02 mm (SD 14.59) from the ipsilateral anterior superior iliac spine at the level of the inguinal ligament. This finding was lower than that described in a multi-ethnic retrospective MRI study based in Chicago by Watson, Bohnenkamp, El-Bitar, Moretti, and Domb, (2014), which averaged at 28.67mm. The findings in our study were close to the vectors measured among African Americans and Hispanics described in the study. This might demonstrate that the femoral nerve distance from the ASIS among Caucasians and Asians as ascribed in the study might be smaller compared to that in Kenyan population.

At the level of the inguinal ligament the mean length of nerve was 72.87mm (SD 19.75) from the midline of the *symphysis pubis*. Overall the described cumulatively averaged medio-lateral distance from the ASIS to the pubic symphysis corresponded with literature findings (Gustafson et al., 2009) with the nerve being at the midpoint of the inguinal ligament. This concurs with the finding in the Kenyan study that the nerve was slightly lateral to the mid – inguinal point. The above findings suggest that in Kenyan population the femoral nerve lies at the midpoint of the inguinal ligament lying averagely 53mm from the ASIS and around 73mm from the midpoint of the pubic symphysis. This therefore approximates the position of the nerve to avoid iatrogenic insults while doing certain approaches to the pelvis and proximal femur including the Ilioinguinal, Stoppa, Iliofemoral and Smith Patterson approaches with reference to the commonly used intraoperative anatomic bony landmarks(Chelly et al., 2010).

5.2 Branching patterns

Similar to two Chinese cadaveric studies by Boo-Chai, (1984) and Yu et al., (2010), the majority of the specimens demonstrated a single branch coursing deep to the Sartorius muscle proximally with some specimens having 2 to 3 sub-branches to the muscle. However, 21.43%, of our specimens had 2-3 twigs arising directly from the anterior branch and coursing deep to the muscle. This finding further augments usability of the Sartorius muscle for muscle compartment transfer in reconstructive arthroplasty.

Innervation to the *rectus femoris* from Kenyan study was from the posterior branch which was mostly through a single branch deep to the muscle, 27(48.21%) (CI 34.66-61.97), or along the medial border, 26(46.43%) (CI 33.99-60.26). This concurred with a Canadian cadaveric study by Yang and Morris, (1999) in which the rectus was innervated by a single muscular branch from the posterior division deep/posterior to the muscle or along the medial border. However, it was not noted to split into 2 branches before entering the muscle as described in the study. Sung et. al., (2003) in a

Korean cadaveric study demonstrated findings which concurred with Kenyan study with the nerve running along the medial border but described 2 subbranches with the superior subbranch running deep with the inferior entering the muscle along the medial border. Therefore, our Kenyan study findings concur with those described in other studies showing no noted interracial/ethnic variability with reference to innervation of the *rectus femoris* from the femoral nerve.

Consideration was made for the innervation of the remaining three *vasti* muscle of the quadriceps *femoris* group. The innervation pattern for the *Vastus lateralis* muscle, almost all, 54 (96.43%) (CI 87.69-99.56), revealed an innervation of a single branch along the medial border of the muscle. There were only two exceptions to this pattern, one with four branches to the medial border of the muscle and another with two branches to the medial border each representing 1.79% (CI 0.05-9.55). Sung et al., (2003) in a Korean cadaveric study demonstrated similar findings but majority of the specimens had 2 subbranches along the medial border. This would suggest no difference in variability in the innervation pattern of the vastus lateralis between Koreans and Kenyan population other than presence of subbranches before perforating the medial aspect of the muscle.

However, unlike the Korean study by Sung et al., (2003), innervation of the *Vastus Intermedius* in Kenyan study was along the medial border, 44(78.57%) (CI 65.56-88.41), with only a few having superficial nerves perforating the muscle 12(21.43%) (CI 11.59-34.44). Both studies however demonstrate a single nerve to the intermedius muscle. Thiranagama, (1990) in a Sri Lankan cadaveric study made mention of the vastus intermedius receiving a nerve slip from lateral branch of the nerve to the vastus medialis but this was not evident in any of the Kenyan specimens dissected. Kenyan study findings therefore concur with the general described consensus on innervation of the femoral nerve. There was however paucity of cadaveric studies further describing the innervation pattern of the vastus intermedius muscle.

Similar to an Indian cadaveric study by Rajput, Rajani, and Vaniya, (2017) and a south African cadaveric study(Nozic, Mitchell, and De Klerk, (1997)), the *vastus medialis* was solely innervated from the posterior branch of the femoral nerve, but no relation to the subsartorial canal was mentioned. It was further described that the nerve further subdivided before entering the substance of the muscle. A southern Asian (Sri Lankan) study by Thiranagama, (1990) involving 30 cadaveric limbs with a higher male ratio made mention of the nerve to vastus medialis within the adductor canal as found in the Kenyan study but describes this branch as the thicker medial branch from the posterior division. Unlike the Kenyan study, there was mention of an additional slender lateral branch which arose directly from the posterior division of the femoral nerve and made no entry into the adductor canal and further innervated the vastus intermedius.

5.3 Observed anatomical branching pattern variations.

Similar to a French cadaveric study by Galtier et. al., (1995) and a Korean study by Sung et al., (2003) no differences were observed between right and left limbs as described in literature. No gender differences were observed as has been described in literature (Astik and Dave, 2011; Galtier et al., 1995; Sung et al., 2003).

In most of the specimen, no anatomical variation was observed 47(83.93%) (71.67-92.38). However, 6 cadaveric specimens (10.71%) (4.03-21.88) demonstrated the nerve branching at the level of the inguinal ligament. A variation described in literature by Das and Vasudeva, 2007 in an Indian cadaveric case report, was observed in 2(3.57%) (0.44-12.31) limbs having a more proximal branching above the level of the inguinal ligament. One cadaveric limb had the femoral nerve branching

30.44mm while the other 27.39mm proximal to the level of the inguinal ligament. This was almost similar to the measurement described at 32mm. Astik and Dave, (2011) demonstrated a similar variation but the measurements were larger at 40mm and 38 mm.

One studied specimen had a more variant anatomy with a slip from the psoas muscle dividing the nerve trunk into two divisions that were uniting 25.88mm proximal to the inguinal ligament. This variation has been described in an Asian cadaveric study by Astik and Dave, (2011) in which the nerve trunk united 40 and 45mm proximal to the inguinal ligament. Variant slips of the iliopsoas major muscles split the femoral nerve into 2 or 3 slips in 35.3% (Anloague and Huijbregts, 2009), 7% (Vázquez et al., 2007) and 2.2% (Spratt et al., 1996). Jelev et al., (2005) reported an accessory iliopsoas muscle which split the left femoral nerve in a female cadaver.

Variant muscular slip of psoas major or accessory slips from iliacus which cause tension of the femoral nerve should be suspected in patients with referred pain to the hip and knee joints(Spratt et al., 1996). This variation is an important differential in persistent knee and hip arthralgia in orthopaedic patients and can be accentuated by hyperextension or external hip rotation.

5.4 Gender stratified sub analysis

A sub analysis was conducted to determine any existing differences between male and female specimen. On comparison of all the measurements between males and females, it was noted that the confidence intervals overlap, an indication that there is no statistically significant differences between the two genders as described in literature(Astik and Dave, 2011; Galtier et al., 1995; Sung et al., 2003).

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The current study looked at the surgical position of the femoral nerve with relation to the commonly used intraoperative bony landmarks at the level of the inguinal ligament. Length of the nerve proximal and distal to the inguinal ligament and muscular branching patterns was assessed.

The course, length, and distribution of the femoral nerve in the Kenyan population concur to some extent with described anatomic studies with some noted variability.

The mean length of the nerve trunk proximal to the inguinal ligament from the anterolateral border of the psoas was 47.85mm (SD 13.719). The nerve trunk ran 29.32 mm (SD 14.239) distal to the inguinal ligament before branching which would suggest a slightly more distal branching point in our population compared to documented findings.

The nerve was found at the midpoint of the inguinal ligament at 53.02 mm (SD 14.59) from the ipsilateral anterior superior iliac spine which is slightly lateral to the midinguinal point at 72.87mm (SD 19.75) from the midline of the *symphysis pubis.*

The branching pattern of the femoral nerve conformed to the described anatomy except 14.29% of the specimens. The most common variation (10.71%) was the nerve branching at the level of the inguinal ligament.

A more variant observation was made in which the nerve was split by a slip from the psoas muscle and then united 25.88mm proximal to the inguinal ligament.

Muscular branching patterns to the quadriceps and Sartorius muscles showed minimal variability and conformed to the described anatomy.

No gender differences were observed.

6.2 Recommendations

1. Surgeons should be aware of the anatomic variations of the femoral nerve and its branches at the level of the inguinal ligament.
2. Approaches to the proximal femur/ pelvis should take into consideration possibility of a more proximal branching of the femoral nerve during deep dissection resulting in inadvertent iatrogenic insult to one or more branches of the femoral nerve.
3. The area at mean length of 53.02 mm (SD 14.59) from the ASIS or 72.87mm (SD 19.75) from the pubic symphysis at the level of the inguinal ligament should be avoided when making incisions to the pelvis/proximal femur as this would place the femoral nerve at risk of iatrogenic insult.
4. Based on the findings of this Kenyan study, the femoral nerve lies at the midpoint of the inguinal ligament averagely 4-7cm from the ipsilateral anterior superior iliac spine which should be considered intraoperatively.
5. More studies on the influence of sex and age on the surgical anatomy of femoral nerve should be conducted.

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Spratt, J. D., Logan, B. M., & Abrahams, P. H. (1996). Variant slips of psoas and iliacus muscles, with splitting of the femoral nerve. *Clinical Anatomy*, *9*(6), 401–404.

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APPENDICES

Appendix 1: IREC Approval letters

INSTITUTIONAL RESEARCH AND ETHICS COMMITTEE (IREC)

MOI TEACHING AND REFERRAL HOSPITAL
P.O. BOX 3
ELDORET
Tel: 33471/2/3

MOI UNIVERSITY
COLLEGE OF HEALTH SCIENCES
P.O. BOX 4606
ELDORET
Tel: 33471/2/3

27th June, 2019

Reference: IREC/2019/143
Approval Number: 0003353

INSTITUTIONAL RESEARCH & ETHICS COMMITTEE
27 JUN 2019
APPROVED
P. O. Box 4606-30100 ELDORET

Dr. Alex Momanyi,
Moi University,
School of Medicine,
P.O. Box 4606-30100,
ELDORET-KENYA.

Dear Dr. Momanyi,

SURGICAL ANATOMY OF FEMORAL NERVE IN FORMALIN PREFIXED CADAVERS IN AN ADULT KENYAN POPULATION

This is to inform you that ***MU/MTRH-IREC*** has reviewed and approved your above research proposal. Your application approval number is ***FAN:0003353.*** The approval period is ***27th June, 2019 – 26th June, 2020.***

This approval is subject to compliance with the following requirements;

i. Only approved documents including (informed consents, study instruments, MTA) will be used
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by ***MU/MTRH-IREC***.
iii. Death and life threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to ***MU/MTRH-IREC*** within 72 hours of notification
iv. Any changes, anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to ***MU/MTRH-IREC*** within 72 hours
v. Clearance for export of biological specimens must be obtained from relevant institutions.
vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days upon completion of the study to ***MU/MTRH-IREC.***

Prior to commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology and Innovation (NACOSTI) https://oris.nacosti.go.ke and also obtain other clearances needed.

Sincerely,

PROF. E. WERE
CHAIRMAN
INSTITUTIONAL RESEARCH AND ETHICS COMMITTEE

cc	CEO	-	MTRH	Dean	-	SOP	Dean	-	SOM
	Principal	-	CHS	Dean	-	SON	Dean	-	SOD

Appendix 2: Hospital Approval (MTRH)

An ISO 9001:2015 Certified Hospital

MOI TEACHING AND REFERRAL HOSPITAL

Telephone :(+254)053-2033471/2/3/4
Mobile: 722-201277/0722-209795/0734-600461/0734-683361
Fax: 053-2061749
Email: ceo@mtrh.go.ke/directorsofficemtrh@gmail.com

Nandi Road
P.O. Box 3 – 30100
ELDORET, KENYA

Ref: ELD/MTRH/R&P/10/2/V.2/2010

28th June, 2019

Dr. Alex Momanyi,
Moi University,
School of Medicine,
P.O. Box 4606-30100,
ELDORET-KENYA.

APPROVAL TO CONDUCT RESEARCH AT MTRH

Upon obtaining approval from the Institutional Research and Ethics Committee (IREC) to conduct your research proposal titled:-

"Surgical Anatomy of Femoral Nerves in Formalin Prefixed Cadavers in an Adult Kenyan Population".

You are hereby permitted to commence your investigation at Moi Teaching and Referral Hospital.

DR. WILSON K. ARUASA, *MBS*
CHIEF EXECUTIVE OFFICER
MOI TEACHING AND REFERRAL HOSPITAL

MOI TEACHING AND REFERRAL HOSPITAL
CEO
APPROVED
JUL 2019
SIGN
P.O. Box 3 - 30100, ELDORET

cc - Senior Director, (CS)
- Director of Nursing Services (DNS)
- HOD, HRISM

Appendix 3: Data collection sheet/form

1. Date…………………………………………………………………………
2. Identification

   code……………………………………………………………………
3. Side of the limb:

   Right……………………….….Left……………………………………
4. Sex of the limb:

   Male………………………….….Female………………….………….
5. Measurement 1

   FN1…………………………………………………………………mm
6. Measurement 2

   FN2……………………………………………………………………mm
7. Measurement 3

   AFN (ASIS to FN at level of inguinal ligament)…………….………….mm
8. Measurement 4

   PFN (pubic tubercle to FN at level of inguinal ligament).………………mm
9. Branching pattern of the femoral nerve:

   a. Anterior branch to pectineus …………………………
   b. Anterior branch to the sartorius………………………
   c. Posterior branch to the rectus femoris…………………….
   d. Posterior branch to the vastus lateralis…………………….
   e. Posterior branch to the vastus intermedius……………………
   f. Posterior branch to the vastus medialis………………..
   g. Any observed anatomical variation (s)? Specify……………………..

Appendix 4: Figures to guide in data collection

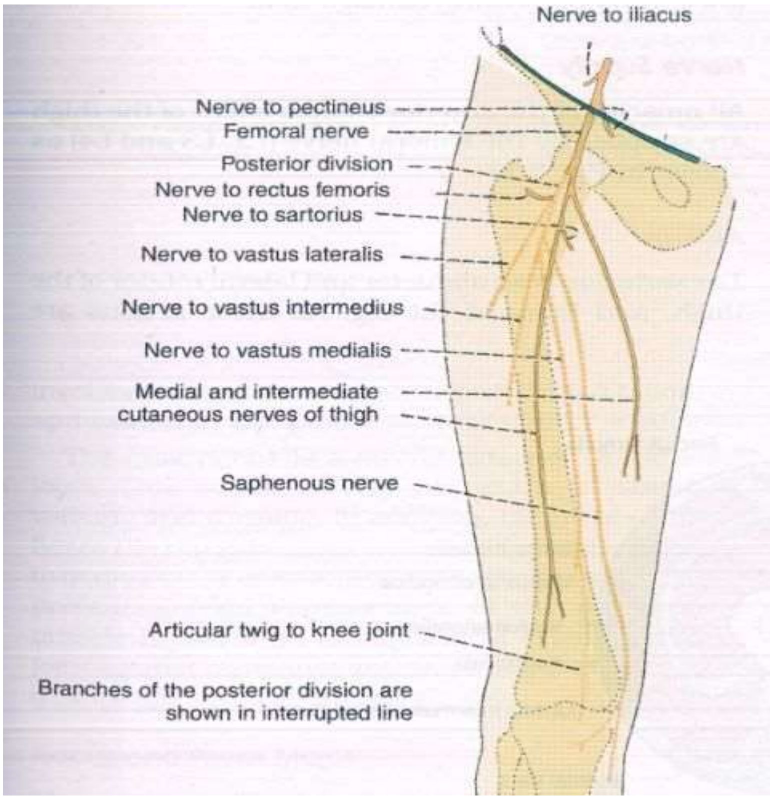

Figure 11: Relation of the femoral nerve to the hip joint and the main branches in relation to the inguinal ligament.(not drawn to scale).

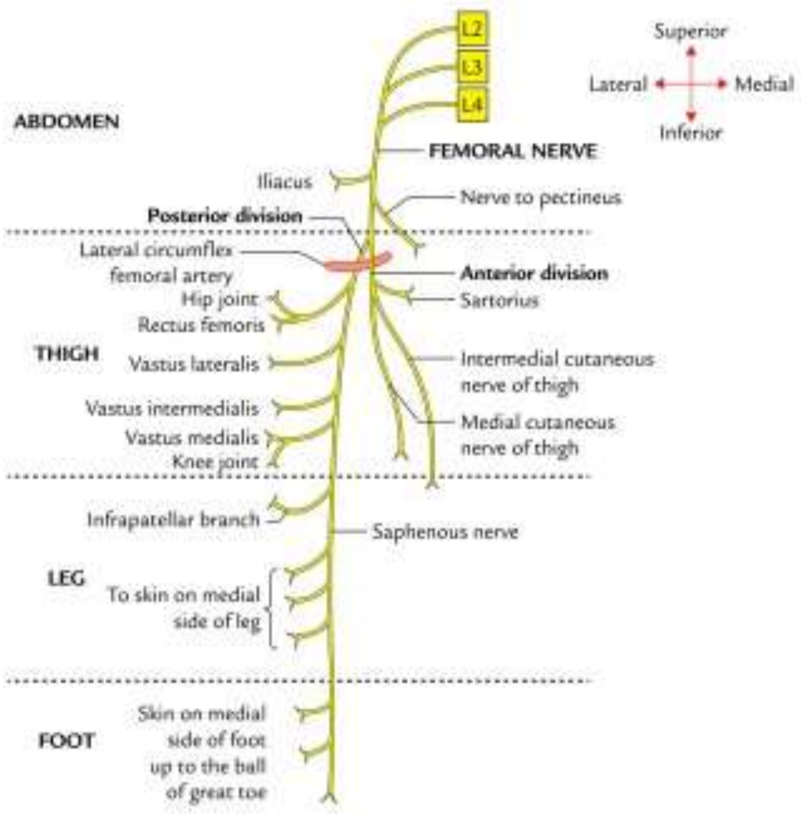

Figure 12: Schematic representation of the branches of the femoral nerve.

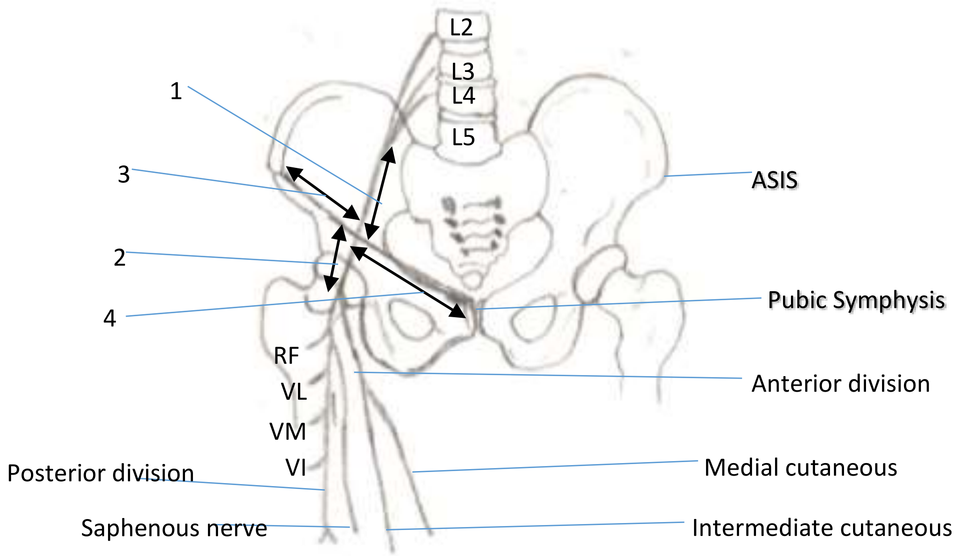

Figure 13: Branches and measurements to be used to map out the femoral nerve.

1) Length of femoral nerve proximal to inguinal ligament but distal to the psoas;

2) Length of femoral nerve distal to inguinal ligament to point of branching into anterior and posterior branches;

3) ASIS to femoral nerve at the level of inguinal ligament;

4) Pubic symphysis to femoral nerve at level of inguinal ligament.

RF) branch to rectus femoris;

VL) branch to vastus lateralis;

VM) branch to vastus medialis;

VI) branch to vastus intermedius

Appendix 5: Budget

Table 5.Budget

ITEM	**AMOUNT (Ksh)**
Digital camera	15,000
Printing and binding services	20,000
Vernier calipers	6,000
Data handling	25,000
Flash disks	3,000
Four rims of plain papers	4,000
Folders	2,000
I.R.E.C fee	2,000
Pens, pencils, rubber	2000
Tape measure	300
TOTAL	**79,300**

NOTE: the researcher will finance the above costs

Appendix 6: Work plan/ Time frame/ Timeline

Table 6.Timeframe

Activity	Duration	Date	Participant(s)
Thesis proposal topic selection and development	1 month	November to December 2018	Researcher and supervisors
Presentation of concept paper to the department	1 month	December 2018 to January 2019	Researcher and supervisors
Proposal writing	4 months	January to April 2019	Researcher and supervisors
Submission and approval of proposal by I.R.E.C		May 2019	Researcher and supervisors
Data collection, coding and cleaning	8 months	January to September 2020	Researcher and supervisors
Thesis write up (results and discussions)	5 months	September 2020 to January 2021	Researcher and supervisors
Submission of thesis for examination	1 month	February 2021	Researcher and supervisors
Oral defense of thesis	1 month	August 2021	Researcher and supervisors