# Morphological Study of an Undescribed Additional Head of Quadriceps Femoris – A Cadaveric and Radiological Study

**Dissertation submitted for**

**M.D Anatomy Degree Branch XXIII Examination,**

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**Chennai, Tamil Nadu.**

**May – 2019**

# DECLARATION

I hereby declare that the dissertation entitled **"Morphological study of an undescribed additional head of Quadriceps femoris – a cadaveric and radiological study"** is a bonafide research work done by me under the supervision of Dr. Suganthy., Professor of Anatomy, Christian Medical College, Vellore, in partial fulfilment of the requirements for the MD Anatomy Branch XXIII examination of the Tamil Nadu Dr. M.G.R. Medical University, Chennai to be held in May 2019.

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MD Anatomy

# CERTIFICATE

This is to certify that **"Morphological study of an undescribed additional head of Quadriceps femoris – a cadaveric and radiological study"** is a bonafide work of **Dr. Femina Sam** in partial fulfilment of the requirements for the M.D Anatomy Branch XXIII examination of The Tamil Nadu Dr. M.G.R. Medical University to be held in May 2019.


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# I. INTRODUCTION

The quadriceps femoris is the powerful extensor muscle of the knee joint present in the anterior compartment of thigh. The quadriceps femoris complex has recently been the subject of renewed interest with regard to histological composition and the anterolateral part of the muscle is frequently chosen for electromyography and skeletal muscle biopsy (1). Delay in the diagnosis of quadriceps tendon injury can result in considerable morbidity due to tendon retraction, fibrosis and muscle atrophy.

The quadriceps femoris usually arises by four heads. The rectus femoris takes origin from anterior inferior iliac spine and from a groove above the acetabulum where as vastus lateralis, vastus medialis and vastus intermedius arises from the upper two-third of the femoral shaft apart from the linea aspera and cover it from trochanter to condyles (2). Distally all the tendons of these muscle bellies unite to form a single tendon to get inserted into the base of patella. The articularis genu muscle is a small muscle located between the vastus intermedius muscle and the prefemoral fat pad. It originates from the anterior surface of the femur and inserts into the suprapatellar bursa. It may be regarded as the fifth head of the quadriceps femoris muscle or as a distal fibre of the vastus intermedius muscle. The function of the articularis genu muscle is to retract and elevate the suprapatellar bursa during knee extension, preventing entrapment of the bursa between the patella and the femur (3).

Quadriceps femoris group of muscles are innervated by independent branches of the femoral nerve and is vascularised through separate muscle branches from lateral circumflex femoral artery (4).

Variations in the deep parts of quadriceps femoris muscle are uncommon while the absence of rectus femoris has been reported. Bergman in his Anatomy Atlas has described a rare slip called rectus accessories, which arose from the tendon at the edge of the acetabulum and inserted into the ventral edge of vastus lateralis (5). Recently, some studies have mentioned about the presence of additional muscle in between vastus lateralis and vastus intermedius in cadaveric dissection and imaging techniques. In another cadaver study, Willan et al. (1990) reported an additional muscle lamina between the vastus lateralis and the vastus intermedius in 36% of the 40 cadavers. Proximally the fleshy lamella was attached to the anterior aspect of the femoral shaft. Distally the muscle belly was usually replaced by a tendinous lamina which contributes to the quadriceps tendon, but occasionally it fused directly with vastus intermedius or vastus lateralis (1). In 2016, Grob et al. identified a separate additional muscle belly in between the vastus lateralis and vastus intermedius in all the 40 dissected thigh studied and they named it as tensor of vastus intermedius. It originated from the anterolateral aspect of the greater trochanter and combined distally into a variable broad, flat tendon or aponeurosis merging into the quadriceps tendon (6). Veeramani and Gnanasekaran in 2017 dissected 36 cadaveric lower limbs and found the presence of the additional muscle head consistently in all the dissected specimens (7).

Radiograph is the most common initial investigation for knee injuries including quadriceps tendon injury. The musculoskeletal sonography has recently gained popularity. The development of high-frequency transducers has markedly increased the image resolution in ultrasonography. Recently, Rajasekaran et al. in 2016 did a retrospective sonographic imaging of the anterior thigh and observed the distal tendinous portion of the tensor of vastus intermedius in all 40 knees of 20 subjects (2).

Although ultrasonography is generally accepted as a useful tool to diagnose quadriceps tendon injury, its reliability has been questioned (8). Magnetic resonance imaging (MRI) has been shown to be the most accurate method of detecting muscle and tendon injuries and assessing the extent of the soft tissue and tendon injuries (9).

A better understanding of the quadriceps tendon anatomy is fundamental for improvement in surgical techniques and for the radiological interpretation of any lesions in the extensor apparatus of the knee joint (10). Till now, there are no MR studies describing the additional muscle head in living human subjects.

The description and knowledge regarding the attachments, variability and morphometry of the additional muscle head of the quadriceps femoris is lacking in South Indian population.

# II. AIM AND OBJECTIVES

## Aim of the study

To confirm the presence of an undescribed additional head of quadriceps femoris by anatomical dissection and radiological techniques

## Objectives of the study

### Cadaveric study

- To locate the attachments of the additional head of quadriceps femoris muscle
- To describe the morphology of the additional head
- To study the motor innervation pattern and vascular supply of the additional muscle head

### Radiological study

- To study the incidence of the additional head of quadriceps in MRI

## III. REVIEW OF LITERATURE

### The Quadriceps femoris muscle

Quadriceps femoris, as the name implies is a four headed muscle. It may also be considered as having a fifth head, the articularis genu, the fibres of which inserts into the suprapatellar recess, unlike the other parts of the quadriceps femoris which have attached to the patellar ligament (11).

The quadriceps femoris, the major extensor of the knee joint, is crucial for human movements such as standing, walking, and running (12). The importance of this muscle is seen in many activities in which the weight of the body falls behind the knee joint. This situation arises in standing up, sitting down, going up and downstairs and climbing. A weak quadriceps femoris muscle, in the knee will be 'giving way' suddenly and unexpectedly (13). The quadriceps femoris is one of the most extensively studied muscle groups in the human body. It has been widely studied clinically, but little attempt has been made to look into the complex morphology of the quadriceps group of muscles (4).

### Origin of quadriceps femoris muscle

Quadriceps femoris, present in the anterior compartment of thigh covers almost all of the front and sides of the femur (14). The rectus femoris arises from the anterior inferior iliac spine and from a roughened area of the ilium immediately superior to the acetabulum. The vastus lateralis originates from the intertrochanteric line of the femur, lateral margin of the gluteal tuberosity and from the upper part of the lateral lip of the linea aspera. The vastus intermedius originates from the upper two-thirds of anterior and lateral surfaces of the femur and the adjacent intermuscular septum. The vastus medialis originates from the intertrochanteric line and continues posteroinferiorly along the pectineal line and from the medial lip of the linea aspera and the medial supracondylar line (15).

## Architecture of the aponeurosis and insertion of the quadriceps femoris

The quadriceps tendon is a multilayered or laminated structure because each of the four components of the quadriceps muscle, the vastus medialis, vastus lateralis, vastus intermedius and rectus femoris may potentially terminate in a separate aponeurotic layer. The insertion of the quadriceps femoris into the patella is traditionally described as a common tendon with a tri-laminar arrangement with the most superficial fibres originating from the rectus femoris, the deepest layer from the vastus intermedius and the intermediate layer from the vastus lateralis and vastus medialis (16). In one anatomic study, a trilaminar arrangement of fibrous tissue structures anterior to the patella from superficial to deep that included a superficial transverse fascial layer, intermediate oblique aponeurotic layer and longitudinally oriented fibers of the rectus femoris tendon was demonstrated (17).

The tendon of the vastus intermedius shows a complex multi-layered structure consisting of a lateral and medial part. The medial part of the vastus intermedius aponeurosis has deep and superficial layers. About 5 to 10 mm medial to the mid-line of the quadriceps tendon, the superficial and deep layer of the medial vastus intermedius aponeurosis fuses with the aponeurosis of tensor of the vastus intermedius and vastus lateralis respectively. The lateral part of the vastus intermedius aponeurosis forms the deepest layer of the quadriceps tendon (10).

Although the usual description of the quadriceps tendon includes three layers, a MRI study revealed that only 56% of the subjects presented with a trilaminar appearance (18,19), 30 % of the subjects were presented with bilaminar quadriceps femoris tendon, 5% presented with a four-layered quadriceps tendon and 7% had only one layer because no fascial boundaries could be distinguished (19). Zeiss et al. studied the MRI appearance of 52 knees with normal tendons. They described that the interpretation of the architecture of the quadriceps tendon is especially difficult in its intermediate layer. They found that the number of laminations was variable, with either two (30%), three (56%) or four layers (6%). In 8% of the knees, the laminations were barely variable (18).

**Actions of the quadriceps femoris**

Quadriceps femoris is the powerful extensor of the knee joint (20). It extends the leg at the knee joint. Unlike the vastus muscles, which cross only the knee joint, the rectus femoris muscle crosses both the hip and the knee joints, so it also assists in the flexion of the thigh at the hip joint. The articularis genu, as it got inserted into the suprapatellar bursa, it pulls the bursa away from the knee joint during extension (21).

Analyses done by Blazevich et al. (2006) revealed that there was a reasonable similarity in the superficial quadriceps muscles, i.e., rectus femoris, vastus medialis and vastus lateralis, which is suggestive of functional similarity. The deep vastus intermedius is architecturally dissimilar and therefore probably serves a different function.

## Biomechanics of quadriceps femoris muscle

The movements of the lower limbs during walking on a level surface are divided into alternating swing and stance phases. The stance phase begins with a heel strike when the heel strikes the ground. Then it begins to assume the body's full weight i.e., loading response followed by midstance phase to stabilize the pelvis and then to heel off and ends with a push off by the forefoot (preswing phase). Quadriceps femoris muscle group are actively involved in loading response. The swing phase begins after push off when the toes leave the ground and ends when the heel strikes the ground (22).

Gross muscle architecture, including the muscle's size and the length and angle of its fibres, is a strong determinant of force production and movement performance (19). Quadriceps muscle provides large forces during pushing or pulling movements and assisting in leg extension during running and jumping. The primary function of the quadriceps femoris group is eccentric deceleration in the early stance phase of gait. The heel strike phase in running is followed by activation of quadriceps femoris, which initially act eccentrically to slow the negative verticals of body velocity, this action lasts till mid support phase. The quadriceps femoris then act concentrically to produce positive vertical velocity of body, both hamstring and quadriceps femoris are active to generate extension at hip (23).

In propelling phase of support, quadriceps is eccentrically active as the heel lifts off and then becomes concentrically active up through toe-off phase. During initial portion of swing phase, quadriceps is active eccentrically to slow rapid knee flexion (23).

In comparison with other primates, humans walk (and run) with the knee joint relatively extended, although during squatting and lifting the knee joint can become flexed acutely. Therefore, the quadriceps must produce forces over large length ranges (19).

**Development of quadriceps femoris muscle**

The skeletal muscles are derived from the paraxial mesoderm which condenses to form somites at the end of 5$^{th}$ week in the human embryo. The somites give rise to the muscles of the neck, trunk and limbs, and the axial skeleton (24). The lower limb buds lie opposite the lower four lumbar and upper two sacral segment and the first indication of limb musculature is observed in the seventh week of development as a condensation of mesenchyme near the base of the limb which is derived from dorsolateral cells of the somites (25).The dorsolateral portion of the somites divide into dermatome and myotome. The myotome differentiates into epimere and hypomere. While the epimere gives rise to the muscle of the back, the hypomere gives rise to infrahyoid muscles, abdominal wall muscles and limb muscles. The hypomere in the region of the lower limb buds migrates into the limb along with the ventral primary rami. The hypomere first forms dorsal and ventral common muscle masses, which later split into primordia of individual muscles (26). (Figure 3.1) Then they begin to differentiate and express muscle specific genes using the transcription factors MEOX2 and PITX2. PAX3 and PAX7 are the important regulators of muscle

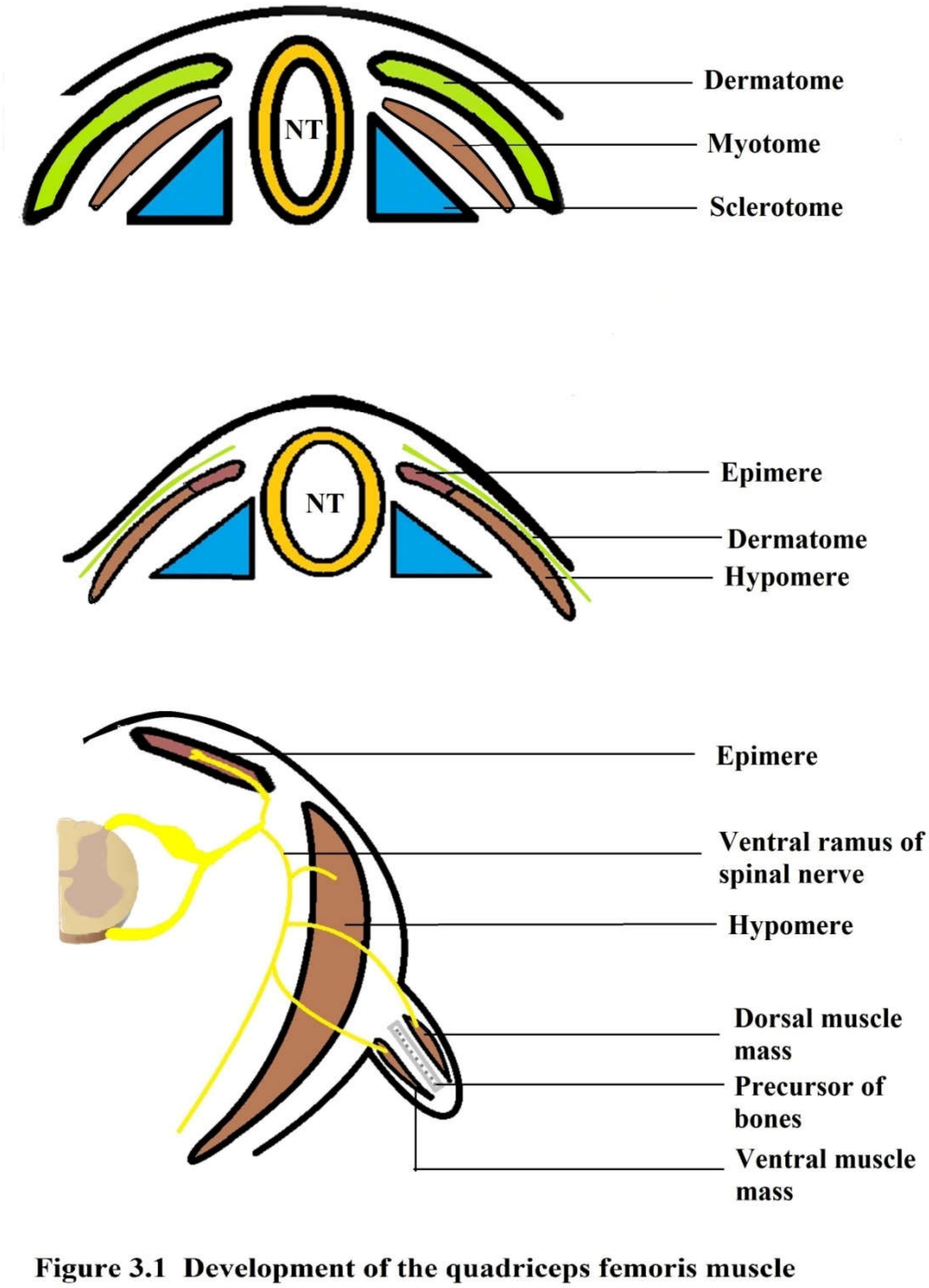



**Figure 3.1 Development of the quadriceps femoris muscle (reproduced from Langman's Medical Embryology and Human Embryology by Inderbir Singh - modified). NT- neural tube**

development (27). Anterior compartment muscles of the thigh including the quadriceps femoris are derived from the dorsal common muscle mass (28).

**Variations of muscles**

Variations in the form, position and attachments of muscles are commonly encountered (29). Absence of a muscle, supernumerary muscles, deviation from the normal course, or an anomalous origin or insertion is seen frequently. Some of these variations may seriously compromise parts of the muscular, vascular, nervous, skeletal or other organ systems (30).

Variations in muscle arise primarily due to our genetic composition, an inheritance carried over from our ancient origins. Many variations are totally benign; some are errors of embryologic developmental timing or persistence of an embryologic condition (30). It was the notion of Galen that the human body has been created in the best possible way, reflecting the perfection of the Creator, and that variations are the result of imperfect or unnatural development. The variations, according to Galen and Vesalius, must be unnatural, the handiwork of the devil (30).

Vesalius noticed several individual variations, hence the abundance in his work of expressions which can be translated into "always", "usually", "frequently", "more frequently", "most frequently", "sometimes", "not always", "rarely", "relatively rarely", "much more rarely", and "very rarely" (31).

**Accessory muscles**

Accessory muscles are anatomic variants representing additional distinct muscles that are encountered along with the normal complement of muscles (32). It has been suggested that the primordium of a muscle undergoes early splitting to form an accessory muscle (29).

Accessory muscles are commonly overlooked by imaging evaluation. Although they are typically asymptomatic and encountered as incidental findings, accessory muscles have been a potential source of clinical symptoms. Such symptoms are usually due to mass effect of the supernumerary muscle, with the patient presenting with either a palpable swelling or secondary compression of adjacent structures such as nerves, vessels, or tendons (32).

**Variations of quadriceps femoris muscle**

Although there are many accessory muscles that have been reported in the lower limb, particularly in the foot and calf like accessory soleus, plantaris, accessory slips of gastrocnemius, accessory peroneus, flexor digitorum accessorius longus, tibiocalcaneus internus, still accessory muscle bellies within the quadriceps femoris are rarely seen (32).

Gray's anatomy textbook has mentioned that quadriceps femoris muscle is rarely subjected to variations and there can be fusion of muscle bellies of vastus lateralis, vastus intermedius and vastus medialis of the quadriceps muscle group (14). Yet a few variations have been described by various authors.

Gruber in 1847 has described variation of quadriceps femoris where he found an additional head which arose from the outer side of the great trochanter, from the line to the linea aspera and from the outer side of the femur. The other head arose from the upper part of the anterior intertrochanteric line in front of the greater trochanter and femur and they were united below (33).

Bergman in his Atlas has mentioned that the deep parts of quadriceps femoris are not subject to many variations. Macalister in 1872 has reported the variation of the quadriceps femoris as follows (5)

- Origin from the anterior superior spine of the ilium was found joining the straight head of rectus femoris
- A split curved head, part being outside, and a part between the layers of the hip-joint capsule
- A double origin from the inferior spine
- A continuity of the acetabular and spinous heads
- With no acetabular origin
- A bursa between the lateral tendon and the brim of the acetabulum
- A double long head
- A large fasciculus of its tendon, passing across the front of the patella, was separated from the bone by the deepest part of the prepatellar bursa
- The relation of this muscle to the rest of the extensor is variable; sometimes at its insertion it is inseparable from the vastus intermedius

- The two vasti uniting over the tendon of this muscle, thus forming a canal in which the rectus tendon ran to its insertion
- Vastus lateralis may be inserted into the outer border of its tendon, while the vastus medialis and vastus intermedius lie beneath
- Vastus lateralis may be bilaminar and united with vastus medialis at its insertion, or to vastus intermedius, or to the rectus, or to a lateral slip of articularis genu

In 2004, Tubbs et al. presented a case of an accessory muscle belly that originated from the intertrochanteric line and travelled distally to approximately midthigh before fusing with the rectus femoris. They termed it as the femoral head of the rectus femoris muscle (34).

In 2006, Tubbs et al. described a third head of rectus femoris in 83 % of the lower limbs dissected. This additional head was found to attach deeply to the iliofemoral ligament and superficially with the tendon of the gluteus minimus muscle as it was attached into the femur (35).

Rarely, a slip called as rectus accessorius may arise from a tendon at the edge of the acetabulum and insert into the ventral edge of vastus lateralis (5). Takeshige et al. (1960) described an anomalous muscle of the anterior thigh that originated from the inguinal ligament and inserted into the proximal part of the vastus medialis muscle. Lewandowski (1994) reported that the rectus femoris muscle was bilaminar.

The articularis genu was also found to be liable to atrophy, absence, splitting, or fusion with vastus intermedius (5).

Lieb and Perry in 1968 described the vastus medialis as being subdivided into two components: a proximal portion referred to as the vastus medialis longus and a distal portion referred to as the vastus medialis oblique. The concept of the vastus medialis oblique has gained increasing acceptance as a separate muscle entity. It is now specifically listed in most research articles as the muscle primarily responsible for controlling the function of the patella and stabilizing the knee joint (36).

The vastus lateralis also has been described to have two parts namely the vastus lateralis oblique and vastus lateralis longus (23). In one case, the vastus lateralis had a bone embedded and was tightly attached to the muscle fibres of the belly (5). Macalister mentioned that the vastus lateralis can be duplicated. The lower end of the vastus lateralis has two laminae and the nerves and the vessels traverse in between the two laminae. It appears that these muscle exhibit great variation in size, shape and fascicle arrangement. Additional bellies of the vastus lateralis have been reported (5).

Variations of vastus intermedius has not been reported much. Sandifort in 1769 reported that it may arise as high as the anterior intertrochanteric line and it may descend as far as a half an inch to an inch above the knee. Omakobia et al (2016) presented a unique case where there was a fusion of the vastus lateralis and vastus intermedius muscle bellies preventing antero lateral thigh flap harvest (37).

Engstrom et al (1991) did a study on the thigh muscle, comparing the anatomical dissection with the radiological methods. Their dissection revealed that there was a little overlap between muscle regions supplied by the nerves to vastus intermedius and vastus lateralis, suggesting that they might be coextensive with the anatomical boundaries of these muscle bellies. However, a discrete anatomical division between vastus intermedius and vastus lateralis by an intervening connective tissue septum was not observed in all transverse sections, particularly in the mid to upper thigh region. Specifically, the muscle bellies were fused for about 25-35 % of their length, with an incomplete posterior division. They confirmed the gross dissection results with the observations in the CT and MR cross-sections. The intermuscular septum was more prominent in the MR. CT images lacked sufficient detail to delineate consistently the boundary between vastus intermedius and vastus lateralis at all section levels (38).

**The description of the additional muscle head**

Recently, an additional muscle head has been described in between vastus lateralis and vastus intermedius both by cadaveric dissection and imaging techniques.

**Cadaveric studies:**

Nwoha et al. (1994) did a study on Nigerian population and described a rare variant of quadriceps femoris muscle found bilaterally in one male out of 200 cadavers. They described that the muscle originated from the femur and inserted into the patella via the common quadriceps femoris tendon. It was supplied by the profunda femoris artery, drained into the profunda femoris vein and was innervated by the femoral nerve. They named it as accessory quadriceps femoris muscle.

In a study done by Willan et al in 1990, they have found a fleshy lamella attached to the anterior aspect of the femoral shaft. Distally the muscle belly was usually replaced by a tendinous lamina which contributed to the quadriceps tendon, but occasionally it fused directly with vastus intermedius or vastus lateralis. Usually the lamina received the extra muscle belly. About in one third of subject, they possessed an additional muscle head associated with vastus lateralis; so it was described as quinticeps femoris. It was present in 27 of the 40 cadavers dissected thighs (36%), bilateral in 10 subjects, unilateral in 7 (1).

Labbe et al. in 2011 presented a case of symptomatic, progressive restriction of knee flexion in a nine-year-old girl. MRI and ultrasound showed the presence of an accessory muscle head of quadriceps femoris. It appeared like an additional vastus intermedius as it was having a separate muscle belly and a tendon. So they described the additional muscle as 'quinticeps' femoris (39). The accessory muscle was fusiform in shape and it was interposed between vastus lateralis and vastus intermedius. The additional muscle belly was 18 cm long, 2.4 cm wide, 1.1 cm thick and half the bulk of the rectus femoris and was attached distally to the quadriceps tendon by a long flat tendon deep to the left vastus lateralis. After the resection of the proximal additional tendon and the muscle belly, the knee flexion got improved. The histological examination of the additional muscle head revealed a normal tendon and had the features of a muscle (39).

Chavan and Wabale (2016), described two distinct parts of vastus lateralis in 35% of cadavers studied namely vastus lateralis longus and vastus lateralis oblique. In all these cases, the plane of separation between vastus lateralis longus and vastus lateralis oblique was fibro fatty tissue. The plane of separation between vastus lateralis longus and vastus lateralis oblique were more pronounced, than the plane of separation between vastus medialis longus and vastus medialis oblique. Vastus lateralis oblique was found in distal portion of vastus lateralis longus. The origin of vastus lateralis oblique was from lateral intramuscular septum. In two specimens, vastus lateralis oblique also found to attach to tensor fascia lata. In one lower limb, there was an additional fleshy belly of vastus lateralis. Proximally it was attached to anterior aspect of shaft of femur and distally its tendon joined to vastus lateralis thus contributing to quadriceps tendon (23).

Grob et al. (2016) did a study on 26 lower limbs and found that the additional muscle was present in all the dissected specimens and named it as tensor of vastus intermedius. He described four morphological types of tensor of vastus intermedius based upon the insertion of its aponeurosis, i.e., the independent-type, vastus lateralis type, vastus intermedius type and common-type. In the independent type, the aponeurosis and the muscle belly of the tensor of vastus intermedius could be clearly distinguished from the aponeurosis of vastus lateralis and vastus intermedius. In the vastus lateralis type, the aponeurosis of the tensor of vastus intermedius passed inseparably into the aponeurosis of the vastus lateralis. In the vastus intermedius type, the aponeurosis of the tensor of vastus intermedius passed inseparably into the aponeurosis of the vastus intermedius. In the common type, the vastus lateralis, the vastus intermedius and the tensor of vastus intermedius presented a common, hardly-divisible origin between the intertrochanteric line and greater trochanter (4). The aponeurosis of the tensor of vastus intermedius inserts through the intermediate layer of the quadriceps tendon on the medial base of the patella. The tensor of vastus intermedius was supplied by the independent muscular and vascular branches of the femoral nerve and lateral circumflex femoral artery. Grob also speculated that anatomically, the aponeurosis of the tensor of vastus intermedius runs adjacent to the descending branch of the lateral circumflex femoral artery. Therefore, rupture to the tensor of vastus intermedius might also cause a rupture of the adjacent vessels and result in haemorrhage (6).

In a study done by Collins et al, additional muscle head was present in 38% of cadaveric thighs (40).

In 2017, Alimohammadi Majid done a study on 88 lower limbs to describe their association with the tensor fascia lata and to confirm the presence of tensor of vastus intermedius and they found that the tensor of vastus intermedius was present in only 45 lower limbs (51%) and there was no apparent association between the tensor of vastus intermedius and the tensor fascia lata (41).

The tensor of vastus intermedius muscle was identified in all the dissected cadavers of South Indian population by a study done by Veeramani and Gnanasekaran. 2017 and supplied by neurovascular pedicle from lateral circumflex branch of femoral artery and posterior division of femoral nerve (7).

**Aponeurosis of the additional muscle head of quadriceps femoris**

The aponeurosis of the additional muscle head consistently fused into the middle layer of the quadriceps tendon and got inserted at the superior medial border of the patella (4).

Grob et al. described that the aponeurosis of vastus intermedius is divided into medial and lateral layers. The medial layer is further divided into superficial and deep.

The medial superficial layer fuses with the aponeurosis of the tensor of vastus intermedius while the lateral part fuses with the aponeurosis of vastus lateralis (10).

It was described that the components of the extensor apparatus of the knee joint consists of layered configuration. It was arranged like the layers of an onion or the “layered husk of corn”. The layers were formed by 1. lateral aponeurosis of the vastus intermedius, 2. deep medial aponeurosis of the vastus intermedius and 3. superficial medial aponeurosis of the vastus intermedius, 4. vastus lateralis, 5. tensor vastus intermedius and 6. rectus femoris (10).

**Neurovascular supply of the quadriceps femoris and its additional muscle head**

**Arterial Supply**

The femoral artery is a continuation of the external iliac artery. It begins behind the inguinal ligament, midway between the anterior superior iliac spine and the pubic symphysis, descends along the anteromedial part of the thigh in the femoral triangle, enters and passes through the adductor (subsartorial) canal, and becomes the popliteal artery as it passes through an opening in adductor magnus near the junction of the middle and distal thirds of the thigh. Its first three or four centimetres are enclosed, with the femoral vein, in the femoral sheath. The femoral artery gives off several branches in the proximal thigh (14).

The profunda femoris artery also called as the deep femoral artery is a large branch that arises laterally from the femoral artery about 3.5 cm distal to the inguinal ligament. The profunda femoris artery gives off the lateral and medial circumflex arteries in the proximal thigh, and perforating and muscular branches more distally.

The lateral circumflex femoral artery is a laterally running branch given off near the root of the profunda femoris artery. It passes between the divisions of the femoral nerve and divides into ascending, transverse and descending branches (14).

The ascending branch ascends along the intertrochanteric line and supplies the greater trochanter, the femoral neck and head. The descending branch descends along the anterior border of vastus lateralis, where it gives off a long branch which descends along the vastus lateralis to the knee, accompanied by the nerve to vastus lateralis. The transverse branch is the smallest passes laterally anterior to vastus intermedius and pierces vastus lateralis to wind round the femur, just distal to the greater trochanter. The vastus lateralis is separated from the vastus intermedius by branches of the femoral nerve and the lateral circumflex femoral artery. The arterial supply of the quadriceps femoris has been traditionally ascribed to a single branch of either the profunda femoris artery or the lateral circumflex femoral artery, the 'artery of quadriceps'. This vessel can be occasionally large and can arise from the femoral artery. The vastus lateralis receives blood supply from the branches of the lateral circumflex femoral artery, 'artery of quadriceps' and from the perforating branch of the profunda femoris artery. The vastus intermedius receives a lateral artery arising from the 'artery of the quadriceps' and a medial artery that arises directly from the profunda femoris artery. The vastus medialis receives the direct branches from the femoral artery (14).

Studies have mentioned that the additional head otherwise known as the tensor of vastus intermedius was vascularized separately through individual branches of the transverse branches of the lateral circumflex femoral artery and side branches of the ascending branch of the lateral circumflex femoral artery (4). Study done on South Indian population revealed that the additional head of the quadriceps femoris was supplied by the branches from lateral circumflex femoral artery (7).

**Nerve Supply**

The femoral nerve is the largest branch of the lumbar plexus and arises from the dorsal divisions of the second to fourth lumbar ventral rami. It descends through psoas major and then passes between psoas and iliacus. Then it passes behind the inguinal ligament into the thigh and it splits into anterior and posterior divisions by the lateral circumflex femoral artery. The anterior division of the femoral nerve gives out intermediate and medial cutaneous nerves of the thigh and muscular branches to sartorius. The branches of the posterior division of the femoral nerve are the saphenous nerve and branches to quadriceps femoris and the knee joint (14).

The nerve to rectus femoris enters its posterior surface and also supplies the hip joint. The branch to vastus medialis lies lateral to the saphenous nerve and femoral vessels, and enters the muscle at about its midpoint. Nerve branches to the vastus lateralis, tensor of vastus intermedius, and lateral portions of the vastus intermedius originates from the lateral deep division of the femoral nerve (4).

The nerve to vastus lateralis forms a neurovascular bundle along with the descending branch of the lateral circumflex femoral artery in its distal part and supplies the knee joint. Two or three branches to vastus intermedius enter its anterior surface about the level of the midthigh (4).

Study done on South Indian population revealed that the additional muscle head of quadriceps femoris was innervated by the posterior division of femoral nerve (7).

**Actions of the additional head of quadriceps femoris**

Owing to the course of the tensor of vastus intermedius from the antero-lateral aspect of the greater trochanter to the medial patella, it can control the movement of the patella in addition to its extensor function of the knee joint. It was hypothesized that the aponeurosis of the additional muscle head that enter the middle layer of the quadriceps tendon from the oblique lateral aspect, counteract all the forces of the medial components of the quadriceps muscle group. As the aponeurosis is in close contact with the vastus intermedius over a long distance, it can exert tension on the vastus intermedius and tightens it medially (6). So they named it as 'the tensor of the vastus intermedius' (4). Similar to the other components of the extensor apparatus, the additional muscle head was acting to power the knee extension as to prevent knee flexion (6).

**Clinical applications of the quadriceps femoris and tensor of vastus intermedius:**

The quadriceps muscle, the extensor of knee joint is three times stronger than it's antagonistic, the hamstrings. By its extension to tibial tuberosity it contributes to stability of patella (23).

The anterolateral thigh flap is now widely established as a versatile flap which can provide ample amounts of skin, muscle and fascia to construct a variety of defects following major head and neck surgery. It is harvested based on the descending branch of the lateral circumflex femoral artery, which is the branch of the profunda femoris artery (37).

Knowledge about the presence of additional muscle head is essential. In some cases the accessory muscle may mimic a soft-tissue tumour. Peres et al presented a case study of a patient with progressive restriction of knee flexion and suggested that it was due to the lack of elasticity of the accessory muscle, which became a tether as the femur grew. Most of the reported symptomatic accessory muscles involve young adults aged between 23 and 25 years, and support the theory of a congenital origin (42). In some sports, the quadriceps tendon injury accounts for around 40% of all injuries, and recurrent trauma can keep an athlete off the field for months. Muscle lesions can be divided into 3 main etio pathogenetic groups:

- lesions caused by direct trauma (contusions)
- those caused by indirect trauma (sprains), which usually occur during eccentric contraction
- lesions caused by cuts (lacerations)

Within the quadriceps femoris, the vastus lateralis and vastus intermedius are the most frequent targets of direct trauma because they are the muscles that are most exposed during activities (43).

The most common complications of quadriceps muscle injury are cicatricial fibrosis, calcification, fluid collections, serohematic pseudocyst formation, and circumscribed intramuscular ossi calcification. Prompt diagnosis within a few days of the muscle trauma is essential to ensure timely and complete healing and to reduce the likelihood of recurrence. For this reason, imaging studies are very important (43).

**Radiological study of quadriceps femoris**

A better understanding of the quadriceps tendon anatomy is fundamental for improvement in surgical techniques and for the radiological interpretation of any lesions in the extensor apparatus of the knee joint (44). Careful attention should be focused on an awareness of commonly encountered variants to improve diagnostic accuracy and avoid misinterpretation (43). Musculoskeletal sonography is safer and more informative than X-rays for evaluating soft tissues pathology (45).

The wide availability of ultrasound equipment, the non-invasiveness and improved technology has placed ultrasound as one of the preferred first-line imaging techniques for investigating musculoskeletal disorders (46). Among the soft tissues, muscles are best visualized by ultrasound examination and ultrasound can be used for direct measurement of muscle size in living human subjects. Researchers have continued to use this non-ionising imaging modality, particularly for obtaining morphometric data on large, superficial muscle groups (38).

Muscle fibres of the quadriceps femoris are usually arranged in a parallel manner and form a sort of pennate structure. The pennate structure is very well demonstrated by ultrasound (47).

Muscle bundles of fibres are seen as hypoechoic zones and the perimysium is seen as hyperechoic lines separating the fibres. Epimysium, fascia, nerves and tendons appear also hyperechoic relative to muscle (47).

Lesions of the quadriceps muscle are frequently seen by sonographers, and mostly they are the results of sports-related trauma. After the healing of muscle injuies, ultrasound can depict some complications such as a cystic lesion or myositis ossificans. Muscle atrophy, inflammation, avulsion and tumours are also good indications for ultrasound (47).

However, this technique lacks clear evidence of its effectiveness in many clinical settings (46).

**Computed tomography (CT Scan)**

Computed tomography has been used extensively to characterize both the size and composition of skeletal muscle (48). But it has not been used for highly detailed, serial investigations of large body structures such as whole limbs in healthy subjects due to the significant exposure to ionising radiation that would be involved with these procedures (38).

**Magnetic Resonance Imaging**

Magnetic resonance imaging (MRI), with its exquisite soft-tissue contrast resolution, is the imaging modality of choice for evaluation of acute traumatic musculotendinous abnormalities (49). MRI in particular holds great potential for clinical and research purposes due to the ability to display high definition images of the musculoskeletal system (50). MRI has several advantages over CT as a diagnostic tool. MRI does not require ionizing radiation nor contrast agents to obtain images. It can give anatomic information in several planes: transaxial, sagittal, and coronal (51).

On MR imaging, thin strands of fat was seen separating the tendons of the individual muscles just above their final junction (52). The quadriceps tendon is seen as a laminated structure on MR images with layers arising from different muscle groups (18).

Whole-body MRI is increasingly used for imaging of systemic muscle diseases and for tumour screening and staging within the musculoskeletal system. Advances in multi-channel whole-body scanners make head to toe high quality images in a practical time frame, a realistic option. Systemic muscle diseases such muscular dystrophy may be detected and evaluated with whole-body MRI technology (50).

In some sports, like soccer and recurrent trauma can keep an athlete off the field for months (43). MR imaging is used for the specific diagnosis of the partial rupture of the tendons of the quadriceps and to measure the accurate extend of injury. The most common mechanism for this injury is eccentric overloading of the extensor mechanism when the knee is flexed with plantar flexion of the foot (53). For both partial and complete tears, many will require imaging with MRI. Complete tears demonstrate an obvious gap between the tendon and the top of the patella with extensive haemorrhage in the gap. Partial tears will demonstrate variable percentages of intact fibres throughout the length of the tendon (54).

**Sonography of the additional head of quadriceps femoris**

Though ultrasound has been routinely done to find out rupture of quadriceps femoris tendon and for other indications like quadriceps tendinosis, pesanserinus tendino bursitis, ilio tibial band friction, baker's cyst, synovitis, septic arthritis, meniscal tears etc. (46), the presence of additional muscle head was demonstrated by ultrasound in one study only. The appearance of the tensor of vastus intermedius has been documented sonographically in forty knees of twenty subjects by Rajasekaran et al. When performing a sonographic evaluation of the anterior thigh, the tendinous portion of the tensor of vastus intermedius was best identified in the transverse plane. At the distal third of the anterolateral thigh, the tendon was located in the fascial plane between the vastus lateralis and vastus intermedius (2). The more proximal aponeurotic and muscular portions of the tensor of vastus intermedius were not as clearly delineated under ultrasound. But the distal aponeurosis of the tensor of vastus intermedius was clearly appreciated.

However, ultrasound procedures have limited resolution and reduced precision for controlling slice thickness and orientation compared to more recent imaging techniques (38).

**MR Imaging of the additional head of quadriceps femoris**

MR imaging has been shown to be the most accurate method of detecting muscle and tendon injuries (55). However, previous studies have mentioned that the intervening tensor of vastus intermedius couldn't be recognised in MRI because it is very difficult to distinguish the fascial or aponeurotic planes between the muscle groups; it reflects the limitations of virtual MR imaging.

A recent study done by Grob et al. (2017) described the two layered configuration of the tensor vastus intermedius. In a preliminary MRI study done by them on three cadaveric lower limbs, the tensor of vastus intermedius couldn't be distinguished from the adjacent vasti despite the fact that the tensor of vastus intermedius could be displayed in the subsequent dissection. So they did MR imaging after dissecting a lower limb and infiltrated with glycerine between the muscle layers to delineate the muscles of quadriceps femoris. They described the multilayered configuration of the quadriceps femoris muscle and the tensor of vastus intermedius was seen to be occupying the intermediate layer (10).

## IV. MATERIALS AND METHODS

Ethical approval for the study was obtained from the Institutional Review Board of Christian Medical College, Vellore.

**Study design:**

Observational study

**Study setting:**

1. Department of Anatomy, Christian Medical College, Vellore
2. Department of Radiology, Christian Medical College, Vellore

**Duration of study:** 2 Years

**Study population:**

- 41 lower limbs from the Department of Anatomy, Christian Medical College, Vellore
- 102 MRI images of lower limbs from the Department of Radiology, Christian Medical College, Vellore
- 12 MRI images of cadaveric lower limbs

**Methods**

1) Cadaveric study

2) Radiological study

- Cadaveric radiological study
- Retrospective radiological study

## 1) Cadaveric study

### Sample size determination

The literature suggests 100% presence of this additional head of quadriceps femoris. (K. Grob et al. 2016; Veeramani and Gnanasekaran 2017) So we assumed a proportion of 90% presence of this additional muscle head. With 10% precision and 95% confidence interval, we got a sample of thirty six lower limbs for dissection study. The following formula was used to calculate sample size

$$N = 4 \times P \times Q / D^2$$

Where, N = Population size; P (Degree of variability) = 90; Q = 10 (100 – P);

D (Allowable error) = 10

### Exclusion criteria

- cadavers with laceration
- damage occurred during the embalming procedure in the femoral region

### Inclusion criteria

The cadavers embalmed with formalin based solution from the Department of Anatomy between the age group of 30 to 70 years of both gender were included in this study.

**Conventional dissection method:**

Forty one lower limb specimens obtained from human cadavers donated for the purpose of teaching and research from the Department of Anatomy, Christian Medical College, Vellore were used for this study. The study was done over a period of 2 years. The limbs belonged to the adult age group (30 -70yrs) of both gender. This included 22 male lower limbs (9 paired and 4 unpaired) and 19 female lower limbs (8 paired and 3 unpaired).

The dissection was carried out as follows:

The thighs were dissected on the basis of a standardized dissection protocol. Each lower limb was placed supine on a dissection table. A horizontal incision was made on the thigh inferior and parallel to the inguinal ligament. At the midpoint of the horizontal incision, a vertical incision was made till few centimetres below the apex of the patella. (Figure 4.1)

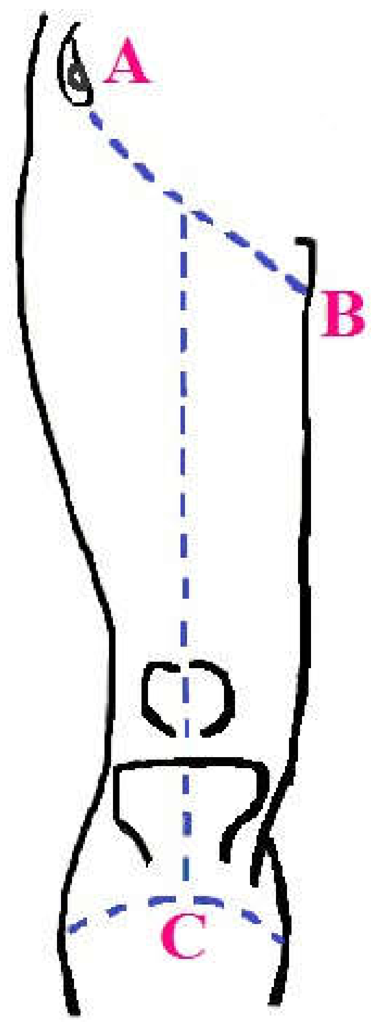



Figure 4.1 A horizontal incision was made on the thigh inferior and parallel to the inguinal ligament from the anterior superior iliac spine to the pubic tubercle (A- B). At the midpoint of the horizontal incision, a vertical incision was made till few centimetres below the apex of the patella (C).

After reflecting the skin, the superficial fascia was removed and the deep fascia (fascia lata) was cut and sartorius muscle was exposed.

Fascia lata over the front of thigh was reflected and the quadriceps femoris muscle was exposed; the vastus medialis; vastus intermedius; vastus lateralis and the rectus femoris muscle with their tendons attaching to the patella.

For better visualization, rectus femoris muscle and sartorius muscle were transected at its distal end and reflected. The vastus intermedius muscle was exposed underneath. Femoral sheath was cut and fascia covering the femoral artery was cleaned and the branches were traced. Femoral nerve was located lateral to the femoral artery and its divisions were traced. All the muscular branches to the quadriceps muscle were traced. The muscle bellies of quadriceps femoris were identified and traced from its origin until they merged with the quadriceps tendon. The presence of an additional muscle head in between the vastus lateralis and vastus intermedius was sought by retracting vastus lateralis laterally. The anatomy of the additional muscle head, if present, was studied with respect to its location, origin, its aponeurosis and neurovascular bundle. The shape of the muscle was noted. The following measurements were taken:

- length, breadth and the thickness of the muscle belly
- length and the breadth of the aponeurosis
- the distance between the fusion of the aponeurosis and the insertion into the patella

The following materials were used to measure different parameters:

a) Inch tape

b) Digital vernier calliper

c) Dissection set

d) Scale

e) Coloured pins

The length of the muscle and its aponeurosis were measured using inch tape. The length of the additional muscle belly was measured from the most proximal to the most distal points at which muscle fibres were seen. The length of the aponeurosis was measured from the most distal point of muscle fibres till it got fused either to the vastus lateralis or vastus intermedius or to the attachment on the superior aspect of patella. The breadth and the thickness of the additional muscle belly and its aponeurosis was measured in their maximum calibre using the digital vernier calliper.

All the dissected specimens were photographed with the help of a digital camera.

## 2. Radiological study

**2a. MRI on Cadaveric limbs:**

Since the additional muscle head of quadriceps femoris was not reported earlier using MR imaging, high resolution MRI scan was done on 12 cadaveric lower limbs to look for the presence of the additional head of quadriceps femoris and followed by anatomical dissection to confirm its presence or absence.

High resolution MRI scan was done in Radiology department using 3 Tesla Philips Achieva and the MR images of 12 lower limbs were acquired in axial and coronal planes using T1 and T2 sequences ( T1 coronal and T1 axial and T2 axial)

**2b. Retrospective Radiological Study:**

**Sample size determination**:

According to the pilot study on fourteen retrospective MRI, we have got a proportion of 60% presence of the additional muscle head. With 10% precision and 95% confidence interval, we got a sample size of 100 MRI of lower limbs for radiological study.

**Inclusion criteria**

The study was done in the Radiodiagnosis Department of Christian Medical College, Vellore. MRI images of 102 patients who attended clinics for various connective tissue disorders such as like inflammatory myositis, anti-synthetase syndrome, inflammatory myopathy, inflammatory polymyositis, pyomyositis, myonecrosis, amyopathic dermato myositis, dermatomyosistis etc. were used for the study. The age of the patients ranged from 8 to 54 years.

Since fourteen MR images were used for pilot study, the data was analysed for 88 MR images.

**Exclusion criteria**

- MRI of lower limbs showing any structural abnormalities
- Fractures, hematoma, tumours involving the femur causing gross distortion of the quadriceps femoris
- Muscle atrophy with fatty degeneration

**Methods**

After confirmation of the presence of the additional head of quadriceps femoris on MRIs of 12 cadaveric lower limbs, a retrospective study of whole body MRI of patients was carried out to study its incidence. 102 MR images (16 males and 35 females) were obtained from patients who attended various clinics were studied. MRI was done using 1.5 Tesla Siemans Magmentom Avantro (A Tim + Dot system) and the MR images of patients were acquired in axial and coronal planes using T1 and T2 sequences (T1 coronal and T1 axial and T2 axial) Age and gender of each patient were recorded.

**Statistical analysis:**

Data was entered in Microsoft excel and statistical analysis was performed using STATA V.13.1. Descriptive analysis was done to find out mean, median and standard deviation of the variables. Fisher's exact test was done to find out whether there were any gender differences in the incidence of additional muscle head in cadavers. Pearson Chi-square test was done to find out whether there is any significant difference between the right and left side of the cadaver.

# V. RESULTS

## 1. Cadaveric study

A total of 41 lower limbs were dissected (22 male and 19 female).The incidence of the additional muscle head present in the study is tabulated in Table 1. The additional muscle head was present in 43.9 % of the lower limbs dissected (95 % confidence interval 28.04, 59.7). The additional muscle head of quadriceps femoris was present in 45.45 % of males and 42.10% in females. There was no significant difference between the genders (p = 0.497) (Table 2; Chart 5.1). This additional muscle head was present more on the left side than on the right side and there was no statistically significant difference between the sides (p value = 0.829) (Table 3). In all cases, the additional muscle head was located between vastus lateralis and vastus intermedius (Figure 5.1). In rest of the limbs, this additional muscle head was absent (Figure 5.2).

**Table 1: Presence of the additional muscle head of quadriceps femoris in comparison with the laterality of the limbs (n=41)**

| | **Total Number of limbs** | | **Presence of additional head** | **%** |
|---|---|---|---|---|
| Paired (17 pairs) | Male (9 pairs) | Right | 4 | 44.44 |
| | | Left | 4 | 44.44 |
| | | Bilateral | 3 | 33.33 |
| | Female (8 pairs) | Right | 2 | 25 |
| | | Left | 3 | 37.5 |
| | | Bilateral | 1 | 12.5 |
| Unpaired (n=7) | Male (n=4) | Right | Nil | Nil |
| | | Left (n=4) | 2 | 50 |
| | Female (3) | Right (n=2) | 2 | 100 |
| | | Left (n=1) | 1 | 100 |

**Table 2: Comparison of incidence of the additional muscle head of quadriceps femoris between males and females**

| Gender | Presence of an additional head | | |
|---|---|---|---|
| | Frequency (n) | % | P value |
| Male (n=22) | 10 | 45.45 | 0.497 |
| Female (n=19) | 8 | 42.10 | |

**Chart 5.1: Bar diagram showing the incidence of additional muscle head of quadriceps femoris in males and females**

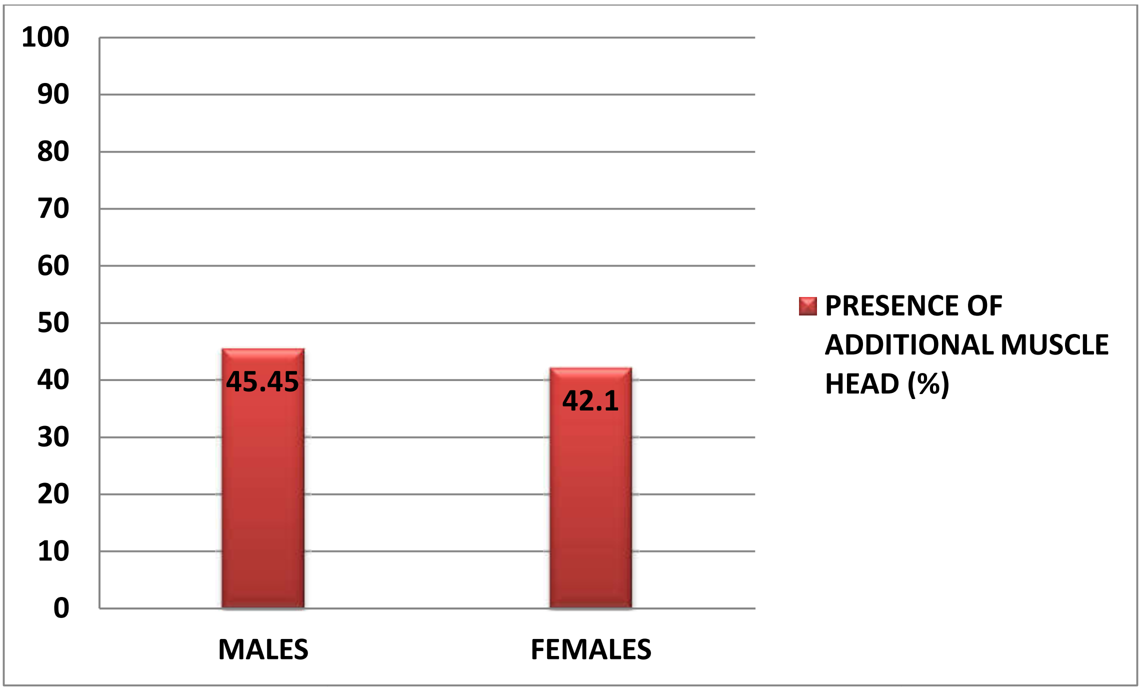


**Table 3: Comparison of the presence of the additional head of quadriceps femoris between right and left side**

| **Side of the lower limb** | **Presence of additional muscle head** | | |
|---|---|---|---|
| | **Frequency (n)** | **%** | **P value** |
| Right | 8 | 42.11 | 0.829 |
| Left | 10 | 45.45 | |

**Origin of the additional muscle head of quadriceps femoris muscle**

The additional head of quadriceps femoris took origin either from the greater trochanter, intertrochantric line, lateral lip of linea aspera or upper one fourth of lateral surface of the shaft of femur (Figure 5.3). Table 4 shows the frequency of the origin of the additional muscle head from different parts of femur. Most often it took origin only from the greater trochanter or along the intertrochanteric line and lateral lip of linea aspera. In one lower limb, the additional muscle head had a conjoint origin with vastus lateralis (Figure 5.4).

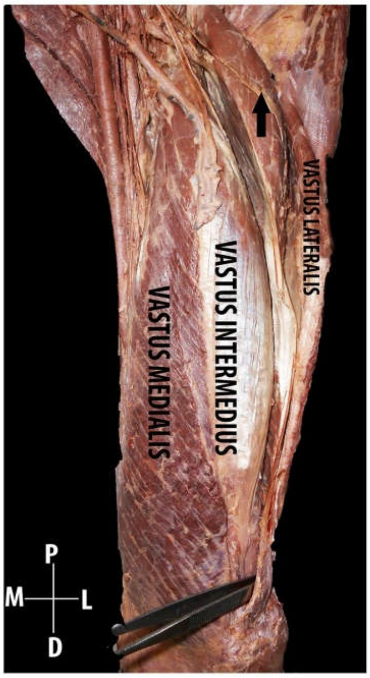



**Figure 5.1:** Anterior view of the left thigh.The rectus femoris and the sartorius were transected and reflected.The additional muscle head(represented by arrow) was seen in between the vastus intermedius and vastus lateralis**.** Distally, it had an aponeurosis and inserted directly into the base of the patella.

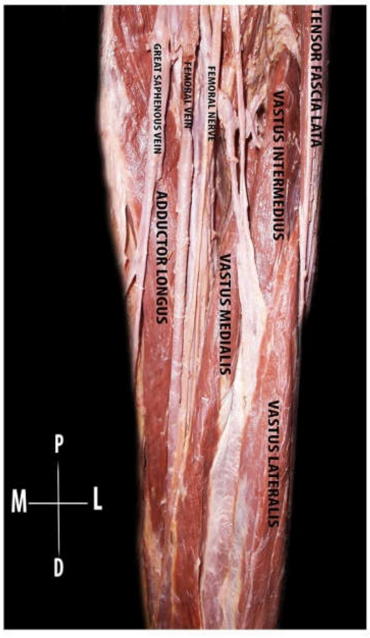



**Figure 5.2.** Anterior view of the left thigh.The rectus femoris muscle was reflected along with the sartorius.The additional muscle head was not seen in between the vastus lateralis and vastus intermedius.


**Figure 5.3.** Schematic diagram showing the origin of the additional head of the quadriceps femoris from the right femur (brown colour shaded areas)


**Figure 5.4**. Anterior view of the right thigh.Proximally, the belly of the additional muscle head had a conjoint origin (black arrow)with the muscle belly of the vastus lateralis.

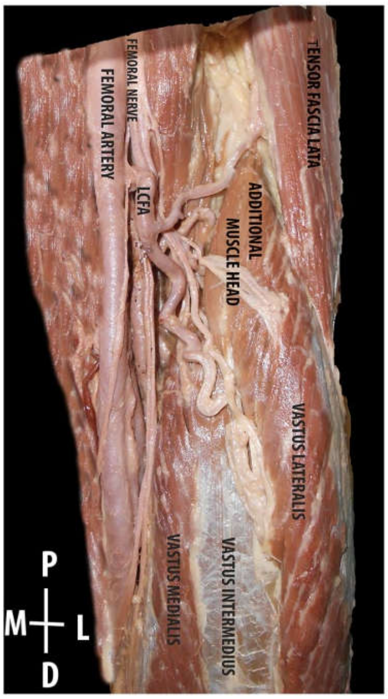



**Figure 5.5:** Anterior view of the left thigh.The additional muscle head with a single muscle belly was present in between the vastus lateralis and vastus intermedius.


**Figure 5.6:** Anterior aspect of the right thigh; The black arrows showing the presence of two additional muscle bellies of the additional muscle head in between the vastus lateralis and vastus intermedius.The additional muscle bellies had no aponeurosis and inserted into the vastus intermedius muscle.

**Table 4: Origin of the additional head of quadriceps femoris muscle**

| **Origin of the additional muscle head** | **Frequency (n)** | **Percentage (%)** |
|---|---|---|
| Greater trochanter | 8 | 44.44 |
| Greater trochanter and intertrochanteric line | 1 | 5.56 |
| Greater trochanter, intertrochanteric line and lateral lip of linea aspera | 1 | 5.56 |
| Greater trochanter and lateral lip of linea aspera | 3 | 16.67 |
| Greater trochanter and lateral surface of the shaft of femur | 2 | 11.11 |
| Intertrochanteric line | 2 | 11.11 |
| Lateral surface of the shaft of femur | 1 | 5.56 |

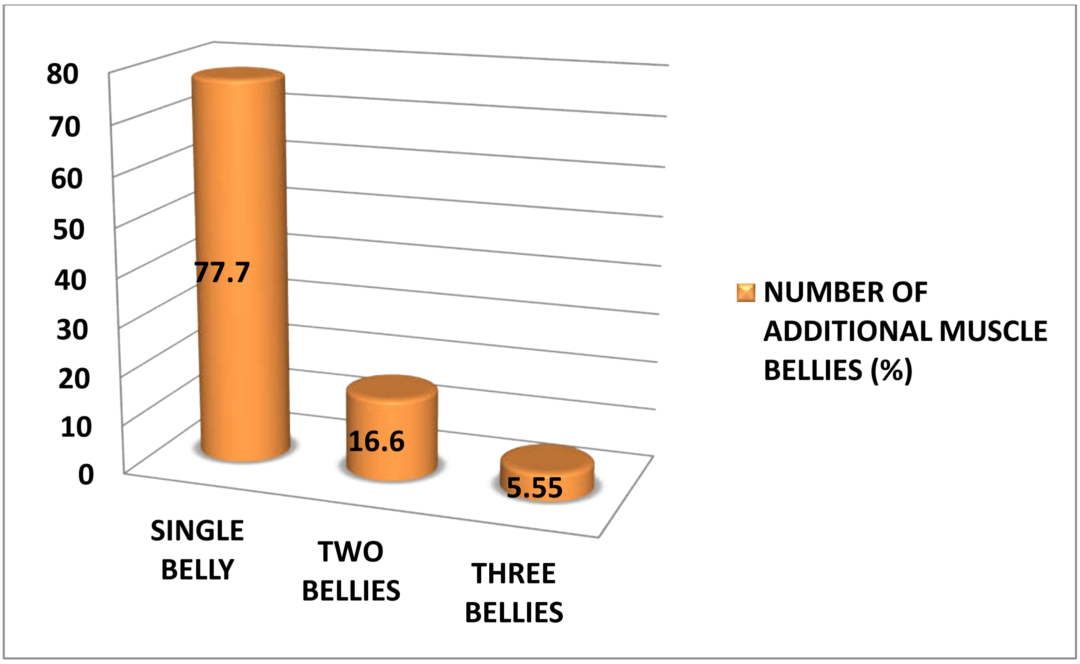
**Number and the shape of additional muscle bellies of quadriceps femoris**

**Table 5: Number of additional muscle bellies of additional muscle head (n = 18)**

| **Total number of muscle heads** | **Incidence of additional muscle head (%)** |
|---|---|
| 1 (n = 14) | (77,77) |
| 2 (n = 3) | (16.66) |
| 3 (n = 1) | (5,55) |

The additional muscle head was presented as a single muscle belly in 77.7 % of lower limbs (Figure 5.5). Two muscle bellies were seen in 16.6 % (Figure 5.6) and three muscle bellies in 5.55% of lower limbs (Table 5, chart 5.2).

**Chart 5.2: Bar diagram showing the incidence of number of additional muscle bellies of additional muscle head of the quadriceps femoris**




**Shape of the additional muscle head of quadriceps femoris**

The additional muscle head was predominantly fusiform in shape followed by quadrilateral and slender shaped muscle bellies (Table 6). (Figures 5.7 a, 5.7 b, 5.7 c)

**Table 6: Different shapes of additional muscle head**

| Number of muscle heads | Shape of the additional muscle head | Frequency (n) | % |
|---|---|---|---|
| One (n =14) | Fusiform | 10 | 55.56 |
| | Quadrilateral | 3 | 16.67 |
| | Slender | 1 | 5.56 |
| Two ( n =3) | Fusiform and slender | 1 | 5.56 |
| | Fusiform and Quadrilateral | 1 | 5.56 |
| | Both heads quadrilateral | 1 | 5.56 |
| Three (n =1) | Two heads fusiform and one quadrilateral | 1 | 5.56 |

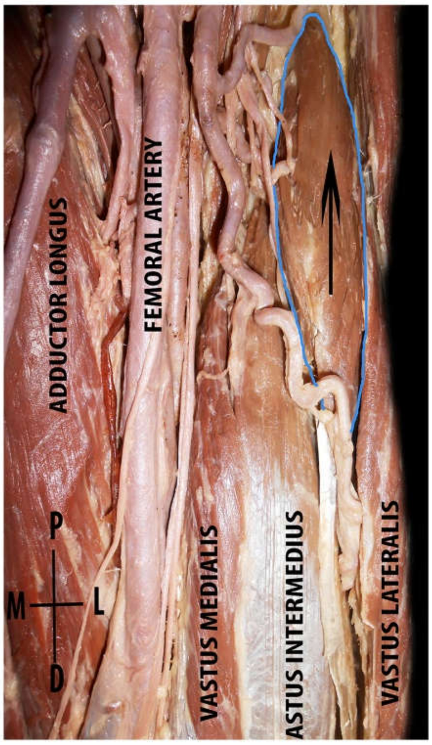



**Figure: 5.7 a**

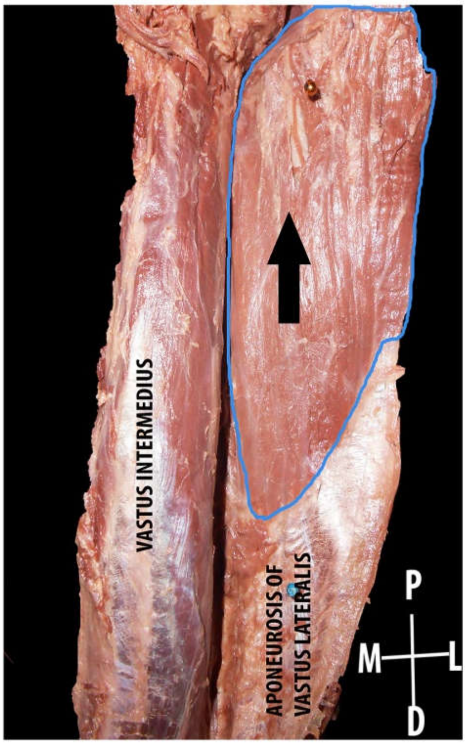



**Figure: 5.7 b**

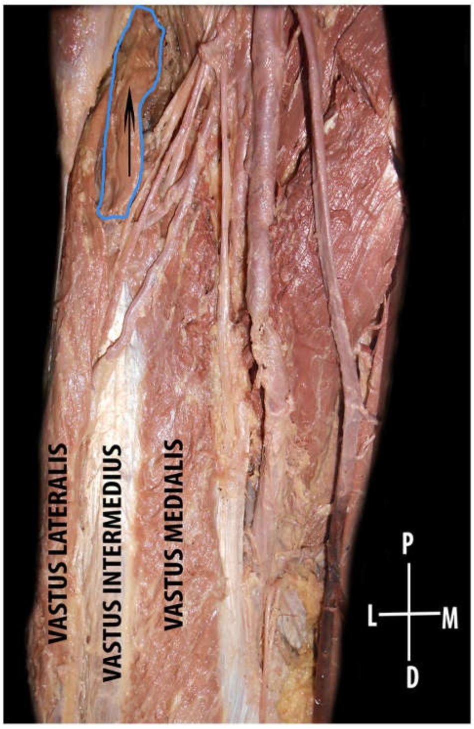



**Figure: 5.7 c**

**Figure: 5.7.** Anterior aspect of the thigh.The additional muscle head of the quadriceps femoris was presented in different shapes like fusiform (Fig 5.7 a), quadrilateral (5.7 b) and slender (5.7 c).

**Quantitative analysis:**

Table 7 shows the descriptive analysis of the variables studied.

**Table 7: Descriptive analysis of the variables**

| Variables | Mean (in cm) | Minimum (in cm) | Maximum (in cm) |
|---|---|---|---|
| Length of the muscle (n=18) | 11.65 ± 2.80 | 7 | 15 |
| Breadth of the muscle (n=18) | 5.99 ± 2.63 | 2.17 | 11.50 |
| Width of the muscle (n=18) | 2.88 ± 1.95 | 0.90 | 7.50 |
| Length of the aponeurosis ( (n=10) | 22.20 ± 7.71 | 2.00 | 27.50 |
| Breadth of the aponeurosis (n = 10) | 5.85 ± 2.07 | 1.50 | 7.50 |
| Aponeurosis of the additional muscle to the base of patella (BOP) (n =18) | 22.25 ± 4.21 | 8.00 | 27.00 |

The maximum length of the additional muscle belly was 15 cm and the minimum was 7 cm with the mean of 11.65 ± 2.80. The breadth of the muscle head ranged from 2.17 cm to 11.50 cm with the mean of 5.99 ± 2.63. The width of the muscle head ranged from 0.9 cm to 7.5 cm with the mean of 2.88 ± 1.95 (Table 7). If there were two or three bellies, the average of the variables was considered. There was no statistically significance between males and females in length, breadth and the width of the additional muscle head of quadriceps femoris. (Table 8)

Similarly, the aponeurosis of the additional muscle head had the maximum length of 27.50 cm with the mean of 22.20 ± 7.71. The breadth of the aponeurosis of the additional muscle head ranged from 1.50 cm to 7.50 cm with the mean of 5.85 ± 2.07. The distance between the formation of the aponeurosis of the additional muscle head to the insertion into the base of patella (BOP) ranged from 8 cm to 27 cm with the mean of 22.25 cm ± 4.21.(Table 7) . There was no statistically significant difference in between males and females in the distance of the attachment of the aponeurosis of the additional muscle head to the base of the patella (BOP). (Table 8)

**Table 8: Comparison of the mean of variables and their significance in males and females**

| **Variables (Mean)** | **Males** | **Females** | **P value** |
|---|---|---|---|
| Length of the muscle | 11.49 ± 2.90 | 11.84 ± 2.86 | 0.80 |
| Breadth of the muscle | 5.98 ± 2.52 | 6.00 ± 2.86 | 0.98 |
| Width of the muscle | 2.43 ± 1.40 | 3.43 ± 2.47 | 0.29 |
| Length of the aponeurosis | 22.00 ± 9.92 | 22.50 ± 3.76 | NA |
| Breadth of the aponeurosis | 5.33 ± 2.48 | 6.63 ± 1.11 | NA |
| Aponeurosis of the additional muscle to the base of patella ( BOP) | 23.45 ± 2.20 | 20.75 ± 5.67 | 0.18 |

**Insertion of the additional muscle head of quadriceps femoris:**

The additional muscle belly of the quadriceps femoris got inserted into either vastus intermedius or vastus lateralis as aponeurosis or directly as a muscle belly (Figure 5.8, 5.6). There was no aponeurosis in 44.4% of the lower limbs. Table 9 shows the different pattern of insertion of the additional muscle head of quadriceps femoris. It was inserted predominantly into the vastus intermedius (55.56 %). In two lower limbs, the additional muscle head formed an aponeurosis and directly inserted into the base of the patella along with the quadriceps tendon (Figure 5.1).

**Table 9: Different types of the insertion of the additional muscle head of quadriceps femoris**

| **Insertion of the additional muscle** | **Frequency** | |
|---|---|---|
| | **n** | **%** |
| Vastus lateralis | 4 | 22.22 |
| Vastus intermedius | 10 | 55.56 |
| One muscle head into the vastus lateralis and other to the vastus intermedius | 1 | 5.56 |
| Both muscle heads to the Vastus Intermedius | 1 | 5.56 |
| Independent insertion | 2 | 11.11 |


**Figure 5.8:** Anterior view of the right thigh.Sartorius was reflexed proximally. Distally, the muscle belly of the additional muscle head (black arrow) had an aponeurosis and inserted into the aponeurosis of the vastus intermedius.

**Blood supply of the additional muscle head of quadriceps femoris**

The additional muscle head got its vascular supply from either the descending or transverse branches of the lateral circumflex femoral artery (LCFA). (Figure 5.9) In one lower limb, the additional muscle head was supplied from the direct branch of profunda femoris artery and in that lower limb, the descending branch of lateral circumflex femoral artery was having a highly tortuous course in the anterior aspect of the thigh in between the additional muscle head of quadriceps femoris and the vastus medialis. (Figure 5.10)

**Nerve supply of the additional muscle head:**

The additional muscle head was innervated either from the direct branch of posterior division of femoral nerve or from the nerve to vastus lateralis or from nerve to vastus intermedius. (Figures 5.11 a, 5.11 b, 5.11 c)


**Figure 5.9 .** Anterior aspect of the proximal third of the right thigh.The additional muscle head got its vascular supply from the transverse branch (black arrow) of the lateral circumflex femoral artery(*).The transverse branch was present in between the muscle bellies of vastus lateralis and the additional muscle head and supplied it from the deeper aspect of the muscle.

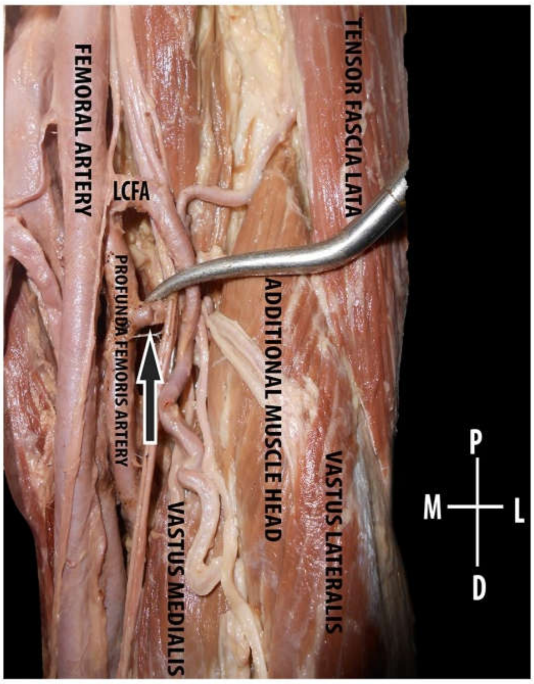



**Figure 5.10 .** Anterior aspect of the proximal third of the left thigh. The additional muscle head was supplied from the direct branch of profunda femoris of femoral artery (black arrow).

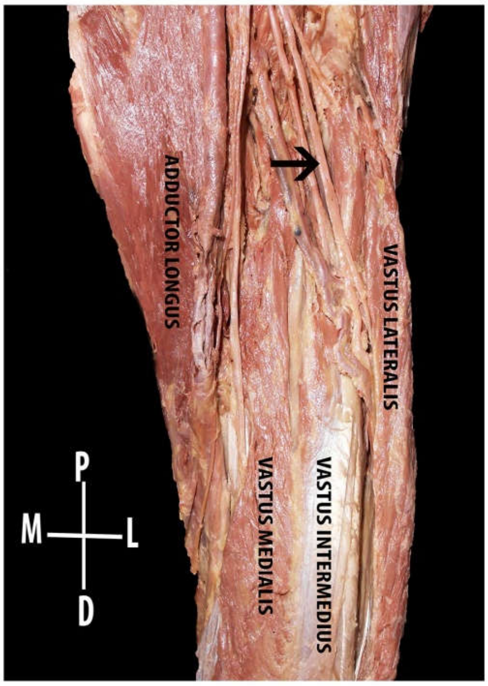



Figure 5.11 a

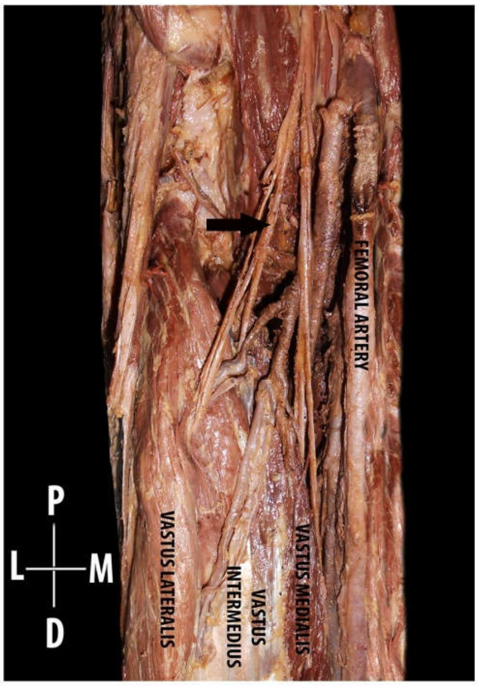



Figure 5.11 b

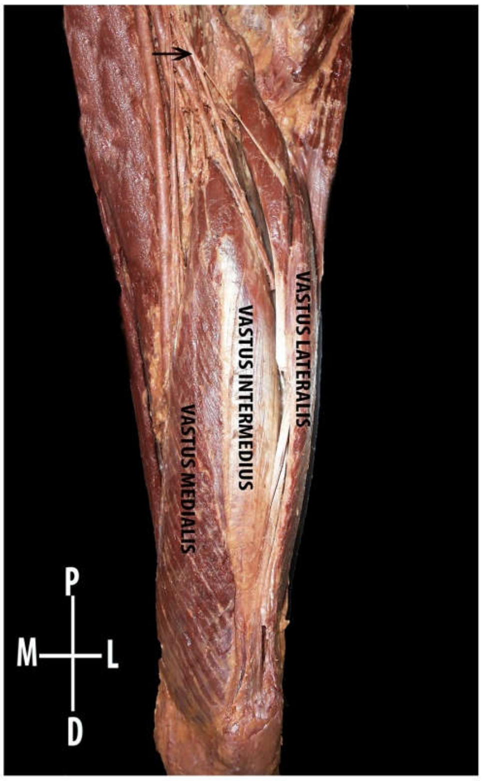



Figure 5.11 c

**Figure 5.11:** Anterior aspect of the thigh; Black arrows indicating the nerve supply of the additional muscle head. The additional muscle head was supplied by direct branch of femoral nerve (Figure 5.13 a), nerve to Vastus lateralis (Figure 5.13 b) or nerve to vastus intermedius (Figure 5.13 c)

## 2. Radiological study:

### MRI on cadaveric lower limbs:

High resolution MRI scan was done in the Department of Radiodiagnosis on 12 cadaveric lower limbs, followed by anatomical dissection to confirm the presence of the additional muscle head. The additional muscle head was present in 4 lower limbs. (Figure 5.12) The concordance rate of dissection and the MRI study was 100 %.

### Retrospective radiological study:

MR images of the lower limb were obtained from 28 female and 16 male patients. The presence of the additional muscle head of quadriceps femoris was looked for on both right and left sides. (Figure 5.13)

The additional muscle head was present in 30.68 % (37.5 % in males and 26.7 % in females) of the retrospective MRIs studied (Table 10).

In males, the additional muscle head was present in 43.75 % on the right side and 31.25 % on the left. In females, it was present in 32.14% on the right side and 21.42% on the left (Table 11, chart 5.3).

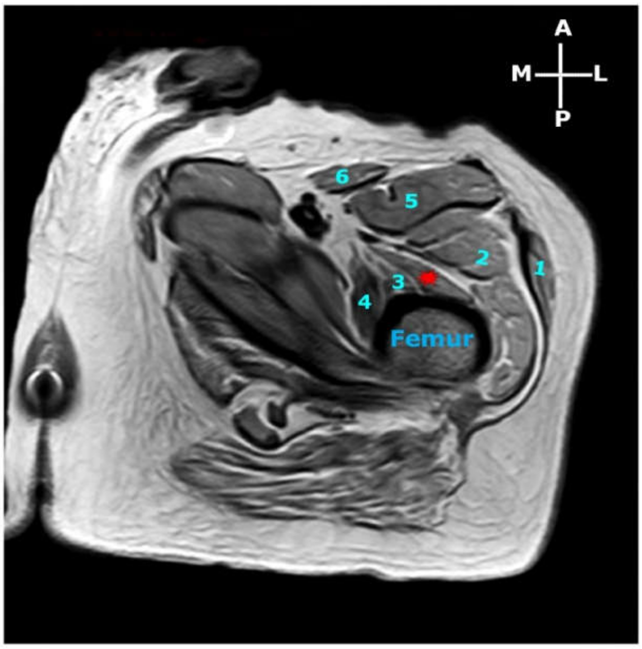



**Figure 5.12:** T2-weighted axial MR imaging of left cadaveric thigh 1- tensor fascia lata 2- vastus lateralis 3-vastus intermedius 4- vastus medialis 5- rectus femoris 6- sartorius.The additional muscle head (✷) is seen in between the vastus lateralis and vastus intermedius seperated by connective tissue septa

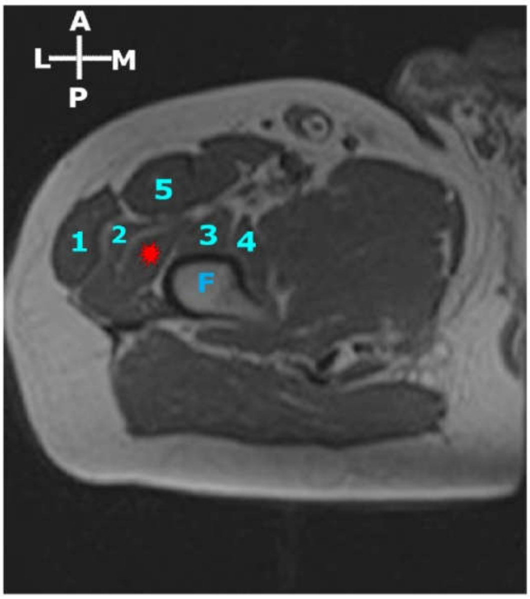



**Figure 5. 13 a**

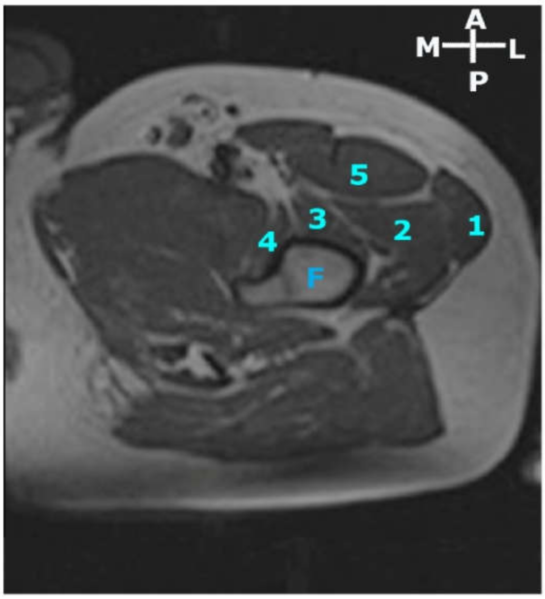



**Figure 5.13 b**

**Figure 5.13** T1-weighted axial MR imaging of lower limb of a patient: 1-tensor fascia lata 2-vastus lateralis 3-vastus intermedius 4- iliopsoas 5-rectus femoris F-femur. Additional muscle head (✷) is seen in between the vastus lateralis and vastus intermedius (5.13 a) and absence of the additional muscle head is depicted in 5.13 b

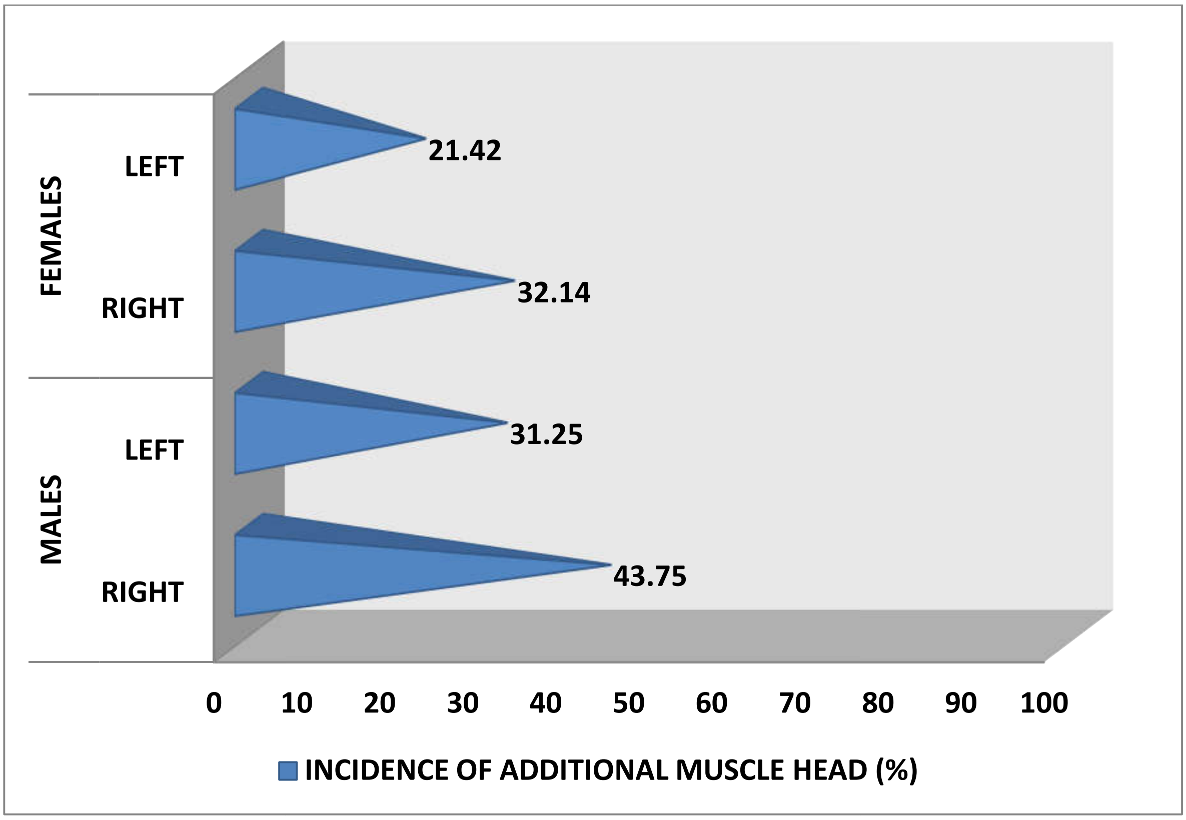
**Table 10: Incidence of the additional muscle head of quadriceps femoris in MR images**

| Gender | Presence of additional muscle head (n = 27) | |
|---|---|---|
| | n | % |
| Males (32) | 12 | 37.5 % |
| Females( 56) | 15 | 26.7 % |

**Table 11: Laterality in the incidence of the additional muscle head of quadriceps femoris in MR images**

| Gender | Side | Presence of additional muscle head | |
|---|---|---|---|
| | | n | % |
| Male | Right (n=16) | 7 | 43.75% |
| | Left (n=16) | 5 | 31.25% |
| Female | Right (n=28) | 9 | 32.14% |
| | Left (n=28) | 6 | 21.42% |

**Chart 5.3: Bar diagram showing the distribution of the additional muscle head in males and females in the retrospective MR images**



## VI. DISCUSSION

The muscles of the anterior thigh, in particular the quadriceps femoris, are not subject to many variations (56). The quadriceps muscle is composed of four parts namely rectus femoris, vastus medialis, vastus lateralis and vastus intermedius. This composite muscle is inserted through a common tendon on patella and through it into the smooth part of tibial tuberosity. Quadriceps femoris muscle, the extensor of the knee joint is three times stronger than its antagonistic group, the hamstrings because it is involved in negatively accelerating the leg and continuously acting against gravity. By its extension to tibial tuberosity it contribute to the stability of patella (23).

Clinicians involved with the musculoskeletal system should be aware of the various anomalies that may exist in the anterior region of thigh. The variations of quadriceps femoris are found particularly in vasti based on the extent of fusion between the three vasti, pattern of laminar arrangement and their insertion on to the base of the patella (14).

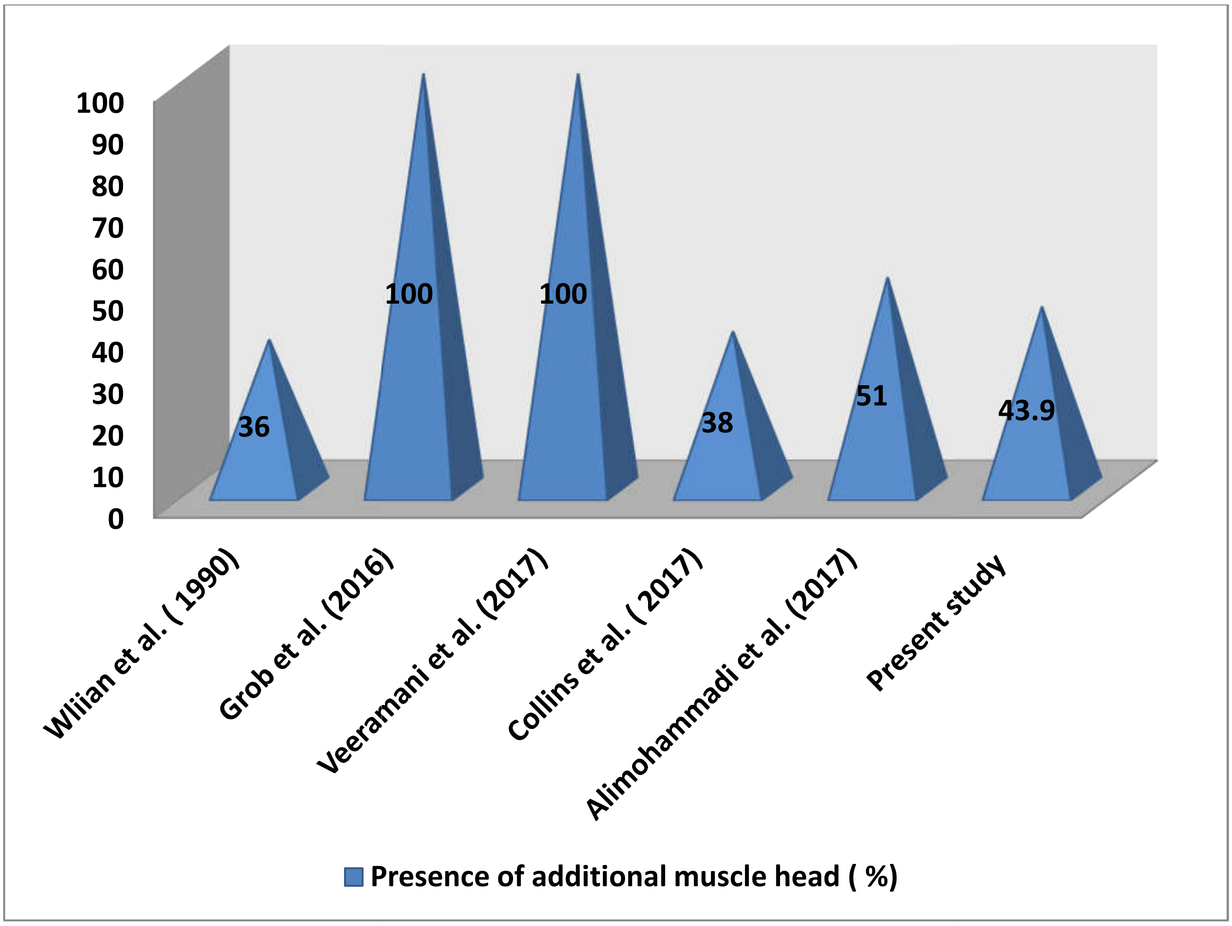
Though it has been reported earlier that variation in the anterior muscle group of thigh are not common, Willan et al. identified for the first time, an additional fleshy lamina between vastus lateralis and vastus intermedius in 27 of the 40 cadavers dissected (36%), bilateral in 10 subjects, unilateral in seven (1). Since then there were a few case reports and studies which described the additional head.

Labbe et al. in 2011 presented a case of symptomatic, progressive restriction of knee flexion in a nine-year-old girl. MRI and ultrasound showed the presence of an accessory muscle head of quadriceps femoris. They dissected the additional muscle belly and found that it was fusiform in shape and interposed between vastus lateralis and vastus intermedius. Following the resection of the additional muscle belly, the knee flexion got regained (39).

In the year 2016, Grob et al reported an additional head in the quadriceps femoris. This study was done on twenty six cadaveric lower limbs and they found an additional head between the vastus lateralis and the vastus intermedius in all the dissected lower limbs and they named it as 'the tensor of vastus intermedius'. Veeramani and Gnanasekaran in 2017 did a study on a total of 36 lower limbs (27 male and 9 female) belonging to South Indian population and they found out that the tensor of vastus intermedius muscle was present in all the dissected lower limbs. It was constantly located between the vastus lateralis and vastus intermedius (7).

Though Grob et al. and Veeramani and Gnanasekaran reported 100% prevalence of the additional muscle head of quadriceps femoris, other studies do not agree with this. Alimohammadi in 2017 did a study on eighty eight lower limbs of forty four cadavers and the tensor of vastus intermedius was found in 51% (45 out of 88) of limbs. (41) Collins et al. in 2017 did a study on eighty donor thighs and found out that the tensor of vastus intermedius was present in 38 % of the thighs dissected (40). In the present study, the incidence of the additional muscle head of quadriceps femoris was 43.9 % which is in accordance to Alimohammadi and Collins et al. Chart 6.1 depicts comparison of the incidence of the additional head of quadriceps femoris between different studies.

**Chart 6.1: Bar diagram showing the distribution of the additional muscle head of quadriceps femoris in various cadaveric studies**




In the present study, though the additional muscle was present more on the left side compared to right side, it was statistically insignificant. In addition, there was no significant difference of its incidence between males and females. There were no other studies to compare the data with.

The additional muscle head was present constantly present in between the vastus lateralis and vastus intermedius which is in accordance with the previous studies by other authors (4,7). This additional muscle head present in between the vastus lateralis and the vastus intermedius has been given less attention so far. That could be due to several reasons as suggested by Grob et al (4).

- proximally, the muscle bellies of the vastus lateralis, the tensor of vastus intermedius, and the vastus intermedius are very close to each and are covered with a complex network of vessels and nerves
- the tensor of vastus intermedius originates at a site very rarely exposed in surgeries
- proximally, the tensor of vastus intermedius continues into an aponeurosis that is very close to the vastus intermedius So, in a cross-section of the thigh, the aponeurosis of the tensor of vastus intermedius is not seen as a muscle but looks like a fascial layer or an intermuscular septum
- the morphology of the tensor of vastus intermedius can differ among individuals

**Number of additional muscle heads of quadriceps femoris**

The additional muscle head of the quadriceps femoris having two muscle bellies was reported in 5 cases by Grob et al (4) and in 3 cases by Veeramani and Gunasekaran (7). In the present study, the additional muscle head had two muscle bellies was seen in 3 cases (16.66 %). In the present study, the additional muscle head having three bellies was noted in one lower limb which has not been reported earlier.

**Shape of the additional muscle head of quadriceps femoris**

The shape of the additional muscle head of the quadriceps femoris has not yet been described in any other studies. In the present study, the shape of the additional muscle has been documented as fusiform shaped (55.56 %) or quadrilateral shaped (16.67 %) or slender (5.56 %). The two bellies of the additional muscle head could be of different shapes i.e., fusiform and slender or fusiform and quadrilateral or both heads quadrilateral. In one case, where the additional muscle head had three bellies, two of the muscle bellies were fusiform shaped and one was quadrilateral in shape.

**Size of the additional muscle head of quadriceps femoris**

The morphometric analysis of the additional head was done in only one study (7). In that study on South Indian population by Veeramani and Gnanasekaran, the mean length of the tensor of the vastus intermedius was 145.40 ± 37.55 mm. The length of the muscle was more in female cadaveric lower limbs (162.59 ± 47.41 mm) when compared to males (139.70 ± 32.72 mm) (7). In the present study on South Indian population, the maximum length of the additional muscle belly smaller than the previous study (Mean - 11.65 ± 2.80 cm) and there was no statistical significant difference between males and females in the length of the additional muscle head, which is again in contrast to the study by Veeramani and Gnanasekaran (7).

The breadth of the additional muscle head ranged from 2.17 cm to 11.50 cm with the mean of 5.99 ± 2.63) and there was no statistical significant difference between males and females in the breadth of the additional muscle head.

The thickness of the additional muscle head ranged from 0.9 cm to 7.50 cm with the mean of 2.88 ± 1.95. There was no statistical significant difference in the thickness of the additional muscle head between males and females. No other studies have mentioned the breadth and thickness of the additional head of quadriceps femoris.

As the aponeurosis of the additional muscle head is in close contact or can be fused with the vastus intermedius over a long distance, it appears to exert tension on the vastus intermedius aponeurosis and medialize the action of the muscle. Hence, the additional muscle head was called as the “tensor of the vastus intermedius” by Grob et al (4).

In the study done by Veeramani and Gnanasekaran (2017), the mean length of the aponeurosis of additional muscle head was 193.55 ± 42.32 mm and the length of the aponeurosis was more in females compared to males (7). In the present study, the length of the aponeurosis of the additional muscle head was much smaller than that of their study [22.20 ± 7.71cm] and there was no gender discrimination.

**Origin of the additional muscle head**

According to Grob et al., the muscle bellies of vastus lateralis, the tensor of vastus intermedius, and the vastus intermedius presented a common, hardly-divisible origin between the intertrochanteric line and greater trochanter (4). Veeramani and Gnanasekaran. described that the tensor of vastus intermedius has its origin either from the upper part of the intertrochantric line, greater tronchanter of the femur, lateral and anterior surfaces of the upper two – thirds of the femoral shaft or it can have a common origin with vastus lateralis and the vastus intermedius (7). In the present study, the additional muscle head of the quadriceps femoris got its origin from the greater trochanter of the femur (44.44 %), from greater trochanter and lateral lip of linea aspera (16.67 %), and also from intertrochanteric line and lateral surface of the shaft of the femur. In one lower limb, the additional muscle head had a common conjoint origin with the vastus lateralis.

**Morphological classification of the additional head of the quadriceps femoris**

Grob et al. classified the additional head of the quadriceps femoris based on the interaction of the aponeurosis with the vastus lateralis and vastus intermedius, as independent-type, vastus intermedius type, vastus lateralis type and a common type where there was a hardly divisible origin between the intertrochanteric line and greater trochanter (57). He reported that the most common type was the independent type. Grob et al. reported the independent type in 42%, followed by the vastus intermedius type and then by vastus lateralis type (4). Alimohammadi reported equal proportion of independent type and vastus intermedius, i.e., 44.4% of each (41). Veeramani and Gnanasekaran in 2017 reported that the independent type was the most common i.e., 33.3 % followed by the vastus lateralis type (7).

In contrast to the previous studies, in the present study, the most common type was the vastus intermedius type where the additional muscle head inserted to the aponeurosis of the vastus intermedius (55.56 %), followed by vastus lateralis type (22.22 %) and then by the independent type which was present in only two lower limbs (11.11 %). Since Grob et al. reported more of the independent type; they called this as a separate muscle and called it as a ‘newly discovered muscle, the tensor of the vastus intermedius' (4). But in the present study, this independent type was seen only in 11.1%, hence this could be considered only as an additional head of the quadriceps femoris, not as a separate muscle.

All the previous studies done on the additional muscle head of quadriceps femoris have mentioned that the additional muscle head constantly had an aponeurosis which got inserted into the base of patella. In the present study, in 44.4% of the lower limbs, the additional muscle head didn't have any aponeurosis. This finding has not yet described in any other previous studies. In such cases, the belly of the additional muscle head of quadriceps femoris was attached directly to the muscle belly of the vastus lateralis or to the vastus intermedius. In some lower limbs having two or three additional muscle bellies, the muscle head got attached to vastus lateralis and vastus intermedius or both the muscle bellies fused with each other distally and got attached to the muscle belly of the vastus intermedius itself.

In the present study, the morphology of the additional muscle was extensively studied and classified based on the number of muscle heads, presence of the aponeurosis and interaction with the nearby muscles i.e., vastus lateralis, vastus intermedius and vastus medialis as follows: (Figure 6.1)

**Type 1: Single muscle head with aponeurosis**

Type 1 a: Independent origin and merges with the vastus lateralis

Type 1 b: Independent origin and merges with the vastus intermedius

Type 1 c: Independent origin and a separate insertion

Type 1d: Fused proximally with the vastus lateralis and distally the aponeurosis merges with the vastus intermedius

**Type 2: Single muscle head with no aponeurosis**

Type 2a: Fused with the vastus lateralis

Type 2b: Fused with the vastus intermedius

**Type 3: Two muscle bellies with aponeurosis**

Type 3a: One muscle belly merges with the vastus lateralis and other to the vastus intermedius.

Type 3b: Both muscle bellies merges with the vastus intermedius

**Type 4**: Three muscle bellies merges with the vastus intermedius

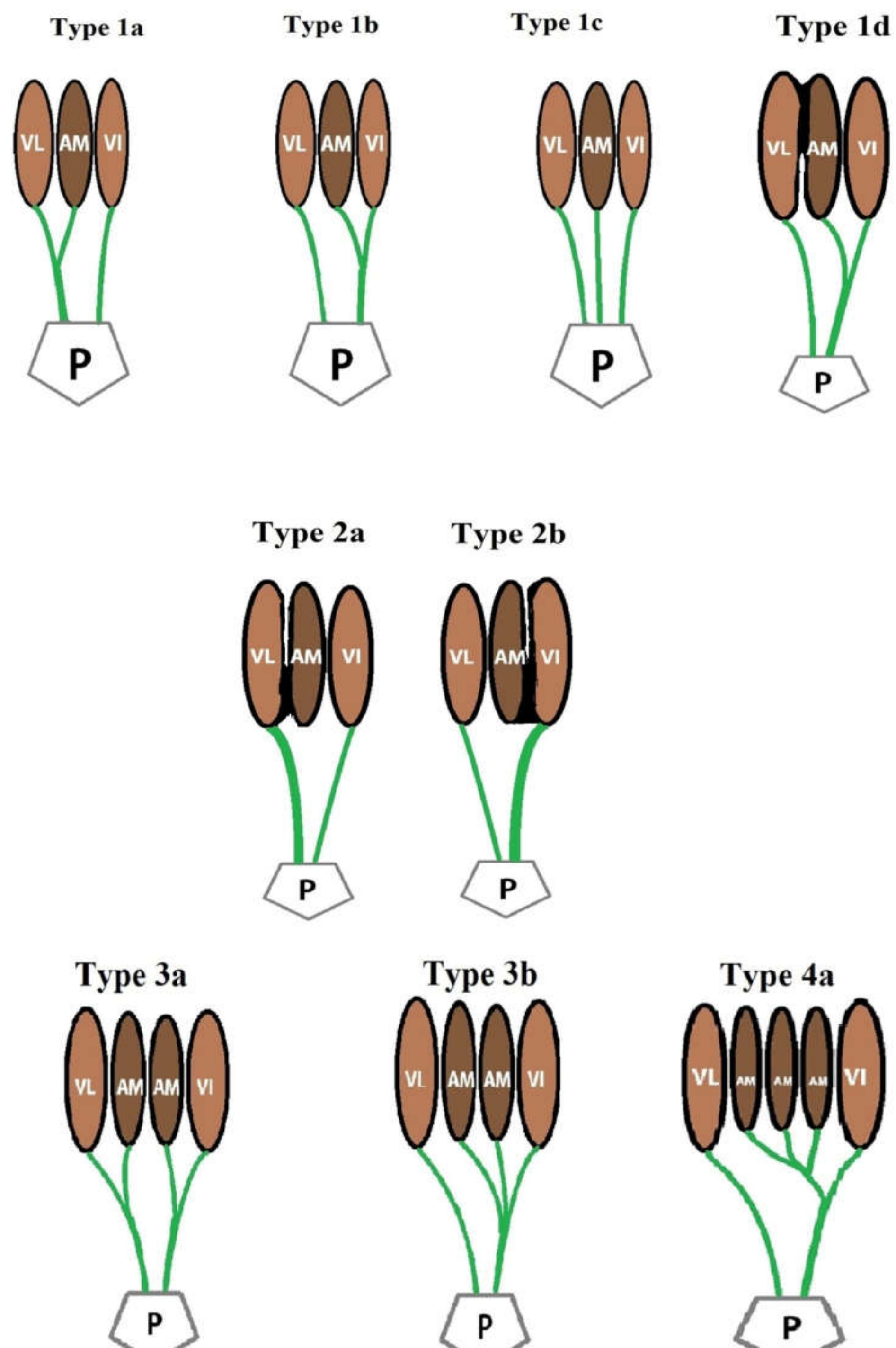



**Figure 6.1 Morphological types of the additional head of quadriceps femoris muscle**
**VI - vastus intermedius; VL - vastus lateralis;**
**AM - additional muscle head; P - Patella**

## Neurovascular supply

The arterial supply to the quadriceps group has been traditionally ascribed to a single branch of either the profunda femoris or of the lateral circumflex femoral called as the ‘artery of the quadriceps'. This vessel can occasionally arise directly from the femoral artery (14). Grob et al. (2016) in his study has mentioned that the tensor of vastus intermedius was supplied by vascular branches lateral circumflex femoral artery which is in accordance with the study done by Veeramani and Gnanasekaran (4,7). It was vascularized separately through individual branches of the transverse branch of the lateral circumflex femoral artery and side branches of the ascending branch of the lateral circumflex femoral artery (4). In the present study, after careful dissection, the additional muscle head was found to be supplied by the transverse or descending branches of the lateral circumflex femoral artery. In one case, the additional muscle head was supplied from the direct branches of the profunda femoris artery. But the additional head was not getting vascular supply from the ascending branch of lateral circumflex femoral artery in contrast to the study done by Grob et al.

In the present study, the vascular supply of the additional muscle head was classified into three types: (Figure 6.2)

**Type 1 -** descending branches of the lateral circumflex femoral artery

**Type 2 -** transverse branches of the lateral circumflex femoral artery

**Type 3 -** direct branch of the profunda femoris of femoral artery

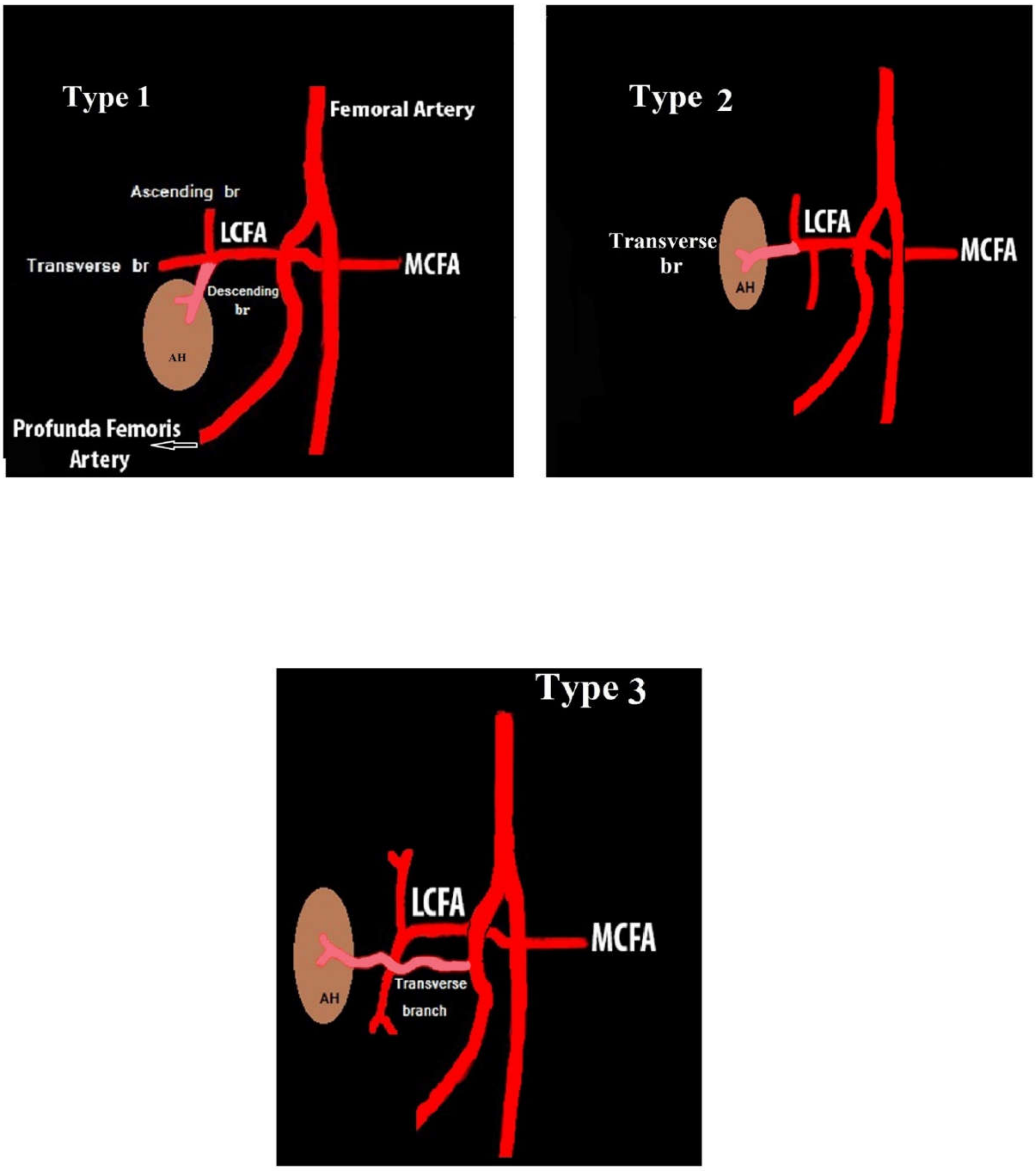



**Figure 6.2** Classification of the arterial supply to the additional head of quadriceps femoris: MCFA-medial circumflex femoral artery LCFA-lateral circumflex femoral artery AH-additional muscle head

In one of the dissected lower limbs, the descending branch of lateral circumflex femoral artery was having a highly tortuous course in the anterior aspect of the thigh in between the additional muscle head of quadriceps femoris and the vastus medialis. While mild tortuosity is a common anomaly without clinical symptoms, severe tortuosity can lead to various serious symptoms. Various forms of tortuous artery have been reported in clinical investigations, most commonly curving/curling, angulation, twisting, looping and kinking vessels. Tortuous vertebral, subclavian and lingual arteries have also been reported. Tortuous iliac and femoral arteries have been reported in some patients and cyclists (58). The tortuosity of the descending branch of the lateral circumflex femoral artery in this case could be due to the compression effect of the additional muscle head proximally.

Anatomically, the aponeurosis of the tensor of vastus intermedius runs adjacent to the descending branch of the lateral circumflex femoral artery. Therefore, rupture to the tensor of vastus intermedius can cause a rupture of the adjacent vessels and result in haemorrhage.

Grob et al. (2016) reported that the tensor of vastus intermedius was supplied by the independent muscular branches of femoral nerve. In the deeper aspect, all the muscle branches supplying the tensor of vastus intermedius had terminal ramifications to the lateral portions of the vastus intermedius (4). Veeramani and Gnanasekaran (2017) described that the additional muscle head of quadriceps femoris was supplied by the posterior division of femoral nerve (7). In the present study, the additional muscle head was innervated either from the direct branch of posterior division of femoral nerve or from the nerve to vastus lateralis or from nerve to vastus intermedius. The nerve supply of the additional muscle head was classified as follows (Figure 6.3)

**Type 1 -** the direct branch of posterior division of femoral nerve

**Type 2 -** from the nerve to vastus lateralis

**Type 3 -** from nerve to vastus intermedius

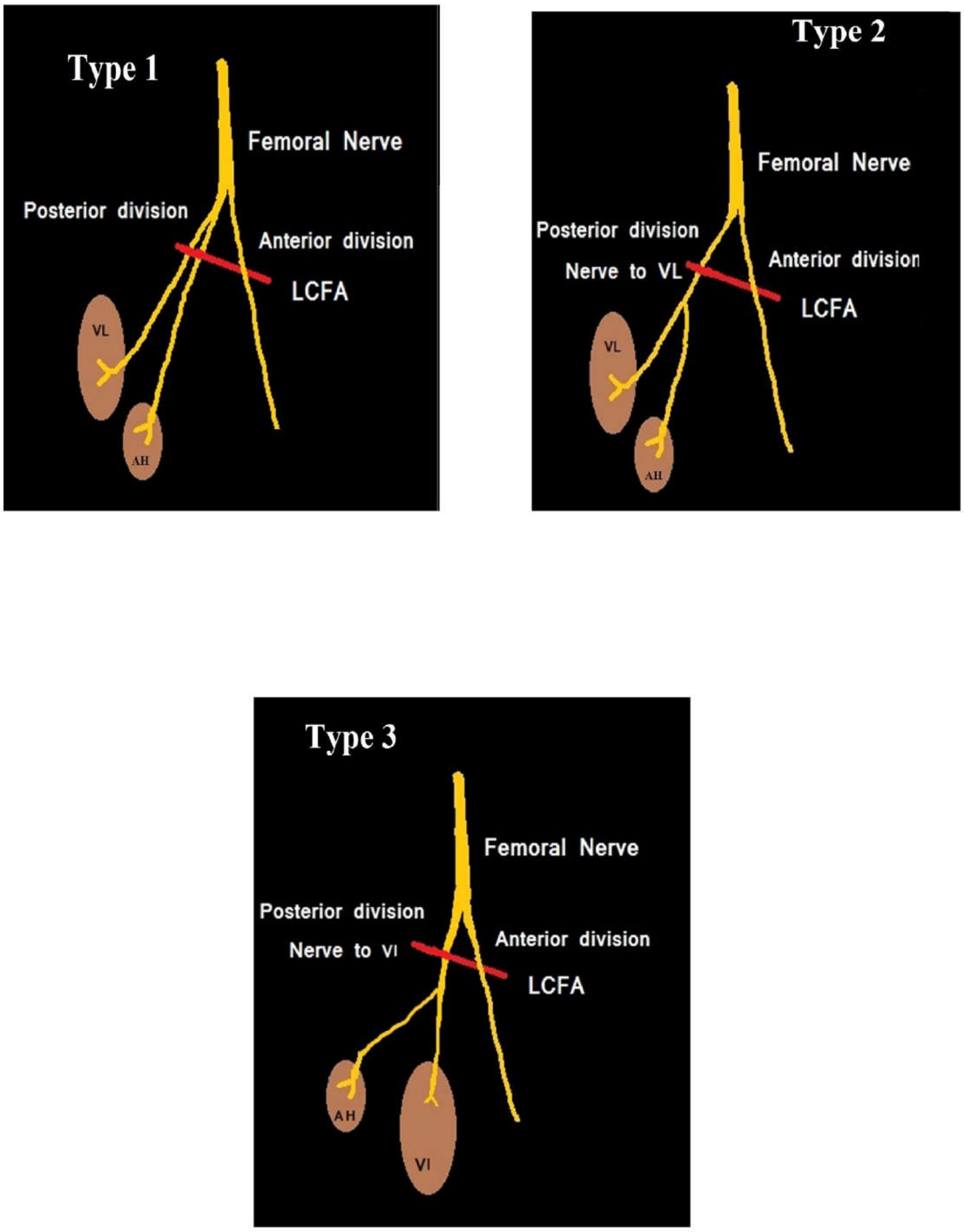



**Figure 6.3** Nerve supply of the additional head of quadriceps femoris AH-additional muscle head VL-vastus lateralis VI- vastus intermedius LCFA-lateral circumflex femoral artery

**Radiological appearance of the additional muscle head**

To understand the role of the additional muscle head of quadriceps femoris in a better manner, knowledge of its gross morphology as well as the radiological features needs to be studied. When ultrasonography is performed by adequately trained personnel with high quality equipment, it offers excellent visualization of the quadriceps femoris muscle and the tendon plane (43).

Recently, Rajasekaran et al. in 2016 did a retrospective sonographic imaging of the anterior thigh and observed the distal tendinous portion of the tensor of vastus intermedius in all 40 knees of 20 subjects. They suggested that the tendinous portion of the tensor of vastus intermedius was best identified in the transverse plane and it was similar to that of the plantaris tendon in the lower leg. Long-axis imaging demonstrated the slender fibrillar appearance of the tensor of vastus intermedius tendon. When the tensor of vastus intermedius tendon was followed distally in the short axis, it began to take an oblique course superficial to the vastus intermedius tendon and deep to the vastus lateralis tendon, forming the deep portion of the intermediate layer of the quadriceps tendon. They concluded that the tensor of vastus intermedius should not be mistaken for focal tendinitis due to the course of the muscle from lateral to medial and it was giving the appearance of focal thickening of quadriceps tendon (2).

Although sonography is generally accepted as a useful means to diagnose quadriceps tendon injury, its reliability has been questioned. MRI has been accurate in assessing the extent of the soft tissue and tendon injuries (8). More recently, MRI has been used to quantify muscle dimensions. In general, the MR images of soft tissue structures, such as individual muscles are more detailed than images from other imaging techniques. In addition to this, highly detailed muscle morphology can be obtained in MR cross-sections (38). MR imaging has become widely accepted as the imaging technique of choice for evaluating acute musculotendinous injuries, allowing accurate evaluation of both normal anatomy and pathology of any vastus muscle or tendon.

Recently, Grob et al did a preliminary MRI study on three cadaveric lower limbs. In their study, the tensor of vastus intermedius could not be distinguished from the adjacent vasti despite the fact that the tensor of vastus intermedius could be displayed in the subsequent dissection. Then they infiltrated the solution of glycerin 86.5% between the displayed layers of the lateral extensor apparatus of the knee joint and found out that a fine intermuscular connective tissue separates the two muscle bellies (55).

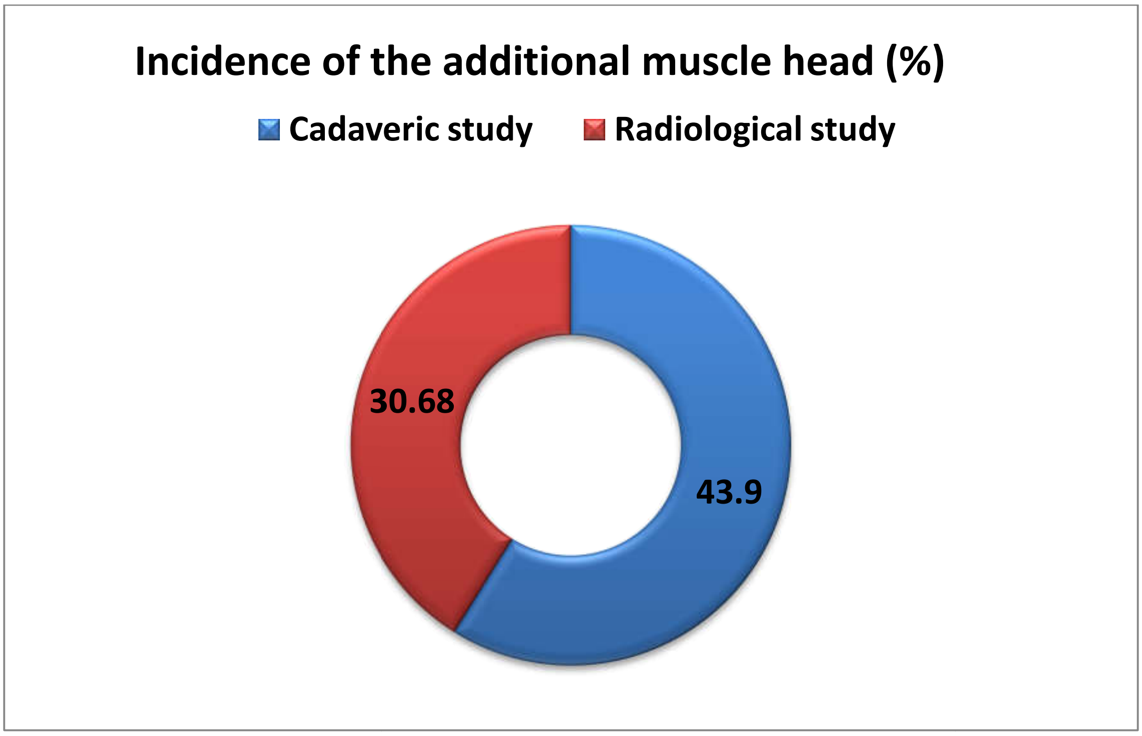
The quadriceps tendon is seen as a multi-layered structure showing a laminated configuration (44). The layers of the distal quadriceps tendon are often interspersed with fibrofatty connective tissue, so the appearance on magnetic resonance imaging will not be homogenously black, as with some tendons, but will have longitudinal streaks of intermediate signal on most sequences (54).

In MRI, the fascia that surrounds each of the vastus muscles is clearly visualized as a thin hyperechoic layer. Their presence helps to distinguish the vastus intermedius from the vastus medialis and rectus femoris (43). Engstrom et al. in 1990 did a comparison of cross section of thighs on anatomic dissection and radiological techniques. He found out that the adjacent muscle bellies of vasti were generally separated by a thin plane of connective tissue but there was no discrete intervening connective tissue septum appreciated between vastus lateralis and vastus intermedius in all the transverse sections of the thigh (38). Pasta et al. in 2010 also reported that it was more difficult to distinguish the vastus lateralis from the vastus intermedius because these two muscles merge with each other laterally (43). This may be the reason why the additional muscle head of the quadriceps femoris has not been noted for a long time by cadaveric dissection and by imaging also. In addition, why this additional head has not been described on MR imaging before could be due to its great variability, unique appearance and closeness to its nearby muscles.

In the present study, MR imaging of the 12 lower limbs was done followed by anatomic dissection to confirm the presence of the additional muscle head. The additional muscle head was present in 4 lower limbs in MR imaging. Then the dissection of the lower limbs was performed and the findings were confirmed. The concordance rate of dissection and the MRI study was 100 % and the present study shows that the MR imaging of the additional muscle head got high sensitivity and specificity.

The additional muscle head has been demonstrated for the first time by MRI. The additional muscle head was present in 30.68 % of the MR images of patients analysed retrospectively. In males, the additional muscle head was present in 43.75 % on the right side and 31.25 % on the left. In females, it was present in 32.14% on the right side and 21.42% on the left.  However, the present study differs from the study done by Rajasekaran et al. who demonstrated 100 % presence of additional muscle head of quadriceps femoris by ultrasonography (2).

**Chart 6.2: Doughnut diagram representing the incidence of the additional muscle head in cadaveric study and radiological study**



This study has demonstrated that the additional muscle head of quadriceps femoris is architecturally different from the description of other previous studies. The additional muscle head is present only in about 43.9 % of the lower limbs. This is the first study to describe the incidence of the additional head of the quadriceps femoris muscle by the retrospective MR imaging.

## VII. CONCLUSION

The presence of the additional muscle head of quadriceps femoris was studied by both anatomical dissection and radiological techniques.

**Cadaveric study**

- The additional muscle head of the quadriceps femoris was present in 43.9% of the lower limbs dissected. It was constantly located in between the vastus laterais and the vastus intermedius
- The additional muscle had either one, two or three muscle bellies which were either fusiform, quadrilateral or slender shaped
- The additional muscle head of quadriceps femoris frequently originated from the greater trochanter and also from intertrochanteric line, lateral lip of linea aspera in addition to greater trochanter or from the upper one fourth of the shaft of femur

- There was no gender discrimination in the length, breadth and thickness of the additional muscle head of quadriceps femoris
- It was inserted into either the vastus lateralis or the vastus intermedius directly as a muscle belly (44.4%) or as an aponeurosis.
- In the present study, the most common type was the vastus intermedius type where the additional muscle head inserted into the aponeurosis of the vastus intermedius (55.56 %), followed by vastus lateralis type (22.22 %) and then by the independent type which was present in only two lower limbs (11.11 %). Since, the independent type was seen only in 11.1%, this could not be considered as a separate muscle as reported by some previous authors.
- The additional muscle head of the quadriceps femoris received its vascular supply from the descending or the transverse branches of the lateral circumflex femoral artery or from the direct branch of profunda femoris artery
- It was innervated from the direct branch of the posterior division of the femoral nerve or from nerve to vastus lateralis or from nerve to vastus intermedius

**Radiological study**

- This is the first study to describe the incidence of the additional head of the quadriceps femoris muscle by MR imaging and it was present in 30.68 % of the images studies
- The concordance rate of the MRI followed by the cadaveric dissection was 100% and the present study shows that the MR imaging of the additional muscle head got high sensitivity and specificity.

## VIII. LIMITATIONS

In the radiological study, the incidence of the additional muscle head of quadriceps femoris was noted only in patients who had musculoskeletal problems, but not in healthy individuals.

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## IX. FUTURE ASPECTS

The quadriceps tendon is commonly involved in many orthopaedic procedures around the knee joint including surgical approaches, tendon injuries or harvesting as a tendon graft. Differences in the laminations and insertion levels of the components of the quadriceps into the patella could affect patellar movement through differences in the angle and magnitude of the forces acting on it and thus can be a predisposing factor for altering the Q angle and thus leads to Patello-femoral joint dysfunction. So further work should be done to find out whether the additional muscle head has a role in the bio mechanics of the knee joint by giving joint stability.

Correlation of existence of the additional muscle head of quadriceps femoris should be done based on the individual's routine life style whether they have a sedentary or non sedentary life style

Further research is needed to find the action of the additional muscle head of quadriceps femoris and whether it can be used as a muscle flap or not.

There has been some research evidence to support that injuries involving the intramuscular tendon injury require prolonged rehabilitation time and may be more prone to recurrence. Improved recognition of injury of the intramuscular tendon may allow more accurate prediction of time to return to sport and thus, reduce risk of recurrence. Therefore, it is important to know whether the additional muscle head has an intramuscular tendon which can best be identified on MRI.

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## XI. ANNEXURES

1. IRB acceptance letter
2. **2.** Proforma for data collection

# OFFICE OF RESEARCH
# INSTITUTIONAL REVIEW BOARD (IRB)
# CHRISTIAN MEDICAL COLLEGE, VELLORE, INDIA

**Dr. B.J. Prashantham,** M.A., M.A., Dr. Min (Clinical)
Director, Christian Counseling Center,
Chairperson, Ethics Committee.

**Dr. Anna Benjamin Pulimood,** M.B.B.S., MD., Ph.D.,
Chairperson, Research Committee & Principal

**Dr. Biju George,** M.B.B.S., MD., DM.,
Deputy Chairperson,
Secretary, Ethics Committee, IRB
Additional Vice-Principal (Research)

December 13, 2016.

Dr. J P Femina Sam,
PG Registrar,
Department of Anatomy,
Christian Medical College,
Vellore – 632 002.

Sub: **Fluid Research Grant NEW PROPOSAL:**
Morphological study of an undescribed additional head of Quadriceps femoris – a cadaveric and radiological study.
Dr. J P Femina Sam, Employment Number: 21335, P G Registrar, Dr. Suganthy Rabi, Employment Number: 30085, Professor and Head, Dr. Ivan James Prithishkumar, Employment number: 28395, Professor, Dr. Koyeli Mary Mahata, Employment number:28450, Assistant Professor, Dr. Madhavi Kandagaddala, Assistant Professor, Employment number:33314, Department of Radiology. Ms. Mahasampath Gowri S, Senior Demonstrator, Department of Biostatistics.

Ref: IRB Min. No. 10421 dated 05.12.2016

Dear Dr. J P Femina Sam,

The Institutional Review Board (**Blue**, Research and Ethics Committee) of the Christian Medical College, Vellore, reviewed and discussed your project titled "Morphological study of an undescribed additional head of Quadriceps femoris – a cadaveric and radiological study" on December 05[th] 2016. I am quoting below the minutes of the meeting.

The Committee raises the following queries:

1. Is there any clinical relevance to doing this study
2. Is there any protocol on how the cadaveric limbs will be transferred to radiology for MRI
3. What is the sensitivity of the MRI of picking up this anomaly in an undissected limb
4. Over which time period will you be doing the MRI

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**Dr. Biju George,** M.B.B.S., MD., DM.,
Deputy Chairperson,
Secretary, Ethics Committee, IRB
Additional Vice-Principal (Research)

Dr. J P Femina Sam and Dr. Ivan James Prithishkumar were present during the presentation of the proposal and satisfactorily responded to the queries raised by the Members. After discussion, it was resolved to **ACCEPT the proposal after receiving the suggested modifications and answers to the queries.**

Note:
1. Kindly HIGHLIGHT the modifications in the revised proposal.
2. Keep a covering letter and point out the answer to the queries.
3. Reply to the queries should be submitted within 3 months duration from the time of the thesis/ protocol presentation, if not the thesis/protocol have to be resubmitted to the IRB.
4. The checklist has to be sent along with the answers to queries.

Email the details to research@cmcvellore.ac.in and send a hard copy through internal dispatch to Dr. Biju George, Addl. Vice-Principal (Research), Principal's Office, CMC.

Yours sincerely,

Dr. Biju George
Secretary (Ethics Committee)
Institutional Review Board.

Cc: Dr. Suganthy Rabi, Department of Anatomy, CMC Vellore.

IRB Min. No. 10421 dated 05.12.2016

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**Dr. Biju George,** M.B.B.S., MD., DM.,
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Secretary, Ethics Committee, IRB
Additional Vice-Principal (Research)


March 08, 2017

Dr. J P Femina Sam,
PG Registrar,
Department of Anatomy,
Christian Medical College,
Vellore - 632 004.

Sub: **Fluid Research Grant NEW PROPOSAL:**
Morphological study of an undescribed additional head of Quadriceps femoris – a cadaveric and radiological study.
Dr. J P Femina Sam, Employment Number: 21335, P G Registrar, Dr. Suganthy Rabi, Employment Number: 30085, Professor and Head, Dr. Ivan James Prithishkumar, Employment number: 28395, Professor, Dr. Koyeli Mary Mahata, Employment number:28450, Assistant Professor, Dr. Madhavi Kandagaddala, Assistant Professor, Employment number:33314, Department of Radiology. Ms. Mahasampath Gowri S, Senior Demonstrator, Department of Biostatistics.

Ref: IRB Min No: 10421 [OBSERVE] dated 05.12.2016

Dear Dr. J P Femina Sam,

The Institutional Review Board (Blue, Research and Ethics Committee) of the Christian Medical College, Vellore, reviewed and discussed your project titled "Morphological study of an undescribed additional head of Quadriceps femoris – a cadaveric and radiological study" on December 05th 2016.

The Committee reviewed the following documents:

1. IRB Application format
2. Proforma
3. Cvs of Drs. Suganthy, Ivan, Koyeli, Madhavi and Ms. Gowri
4. No. of documents 1- 3

The following Institutional Review Board (Blue, Research & Ethics Committee) members were present at the meeting held on December 05th 2016 in the BRTC Conference Room, Christian Medical College, Bagayam, Vellore 632002.



Ethics Committee Blue, Office of Research, 1st Floor, Carman Block, Christian Medical College, Vellore, Tamil Nadu 632 002
Tel: 0416 – 2284294, 2284202 Fax: 0416 – 2262788, 2284481 E-mail: research@cmcvellore.ac.in

**OFFICE OF RESEARCH**
**INSTITUTIONAL REVIEW BOARD (IRB)**
**CHRISTIAN MEDICAL COLLEGE, VELLORE, INDIA**

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March 08, 2017

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Department of Anatomy,
Christian Medical College,
Vellore - 632 004.

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**Dr. Biju George,** M.B.B.S., MD., DM.,
Deputy Chairperson,
Secretary, Ethics Committee, IRB
Additional Vice-Principal (Research)


| Name | Qualification | Designation | Affiliation |
|---|---|---|---|
| Dr. Biju George | MBBS, MD, DM | Professor, Haematology, Research), Additional Vice Principal , Deputy Chairperson (Research Committee), Member Secretary (Ethics Committee), IRB, CMC,Vellore | Internal, Clinician |
| Dr. B. J. Prashantham | MA(Counseling Psychology), MA (Theology), Dr. Min (Clinical Counselling) | Chairperson, Ethics Committee, IRB. Director, Christian Counseling Centre, Vellore | External, Social Scientist |
| Dr. Ratna Prabha | MBBS, MD (Pharma) | Associate Professor, Clinical Pharmacology, CMC, Vellore | Internal, Pharmacologist |
| Dr. Rekha Pai | BSc, MSc, PhD | Associate Professor, Pathology, CMC, Vellore | Internal,Basic Medical Scientist |
| Rev. Joseph Devaraj | BSc, BD | Chaplaincy Department, CMC, Vellore | Internal, Social Scientist |
| Mr. C. Sampath | BSc, BL | Advocate, Vellore | External, Legal Expert |
| Dr. Simon Pavamani | MBBS, MD | Professor, Radiotherapy, CMC, Vellore | Internal, Clinician |
| Dr. Rajesh Kannangai | MD, PhD. | Professor, Clinical Virology, CMC, Vellore | Internal, Clinician |
| Ms. Grace Rebekha | M.Sc., (Biostatistics) | Lecturer, Biostatistics, CMC, Vellore | Internal, Statistician |
| Mrs. Pattabiraman | BSc, DSSA | Social Worker, Vellore | External, Lay Person |
| Dr. Anuradha Rose | MBBS, MD, MHSC (Bioethics) | Associate Professor, Community Health, CMC, Vellore | Internal, Clinician |
| Dr. Balamugesh | MBBS, MD(Int Med), DM, FCCP (USA) | Professor, Pulmonary Medicine, CMC, Vellore | Internal, Clinician |

IRB Min No: 10421 [OBSERVE] dated 05.12.2016 3 of 4

# OFFICE OF RESEARCH
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**Dr. Biju George,** M.B.B.S., MD., DM.,
Deputy Chairperson,
Secretary, Ethics Committee, IRB
Additional Vice-Principal (Research)


| | | | |
|---|---|---|---|
| Dr. Santhanam Sridhar | MBBS, DCH, DNB | Professor, Neonatology, CMC, Vellore | Internal, Clinician |
| Mrs. Emily Daniel | MSc Nursing | Professor, Medical Surgical Nursing, CMC, Vellore | Internal, Nurse |
| Dr. Mathew Joseph | MBBS, MCH | Professor, Neurosurgery, CMC, Vellore | Internal, Clinician |

We approve the project to be conducted as presented.

Kindly provide the total number of patients enrolled in your study and the total number of withdrawals for the study entitled: "Morphological study of an undescribed additional head of Quadriceps femoris – a cadaveric and radiological study" on a monthly basis. Please send copies of this to the Research Office (research@cmcvellore.ac.in).

*Fluid Grant Allocation:*

*A sum of 41,000/- INR (Rupees Forty one thousand Only) will be granted for 2 years.*

Yours sincerely,

Dr. Biju George
Secretary (Ethics Committee)
Institutional Review Board

Dr. BIJU GEORGE
MBBS ... M
SECRETARY ... EE)
Instit...
Christian Medical C... 002.

IRB Min No: 10421 [OBSERVE] dated 05.12.2016



Ethics Committee Blue, Office of Research, 1st Floor, Carman Block, Christian Medical College, Vellore, Tamil Nadu 632 002
Tel: 0416 – 2284294, 2284202 Fax: 0416 – 2262788, 2284481 E-mail: research@cmcvellore.ac.in

**PROFORMA FOR DATA COLLECTION – Cadaveric study**

| | |
|---|---|
| Specimen No. | |
| Side | Right / Left |
| Sex | Male / Female |
| Existence Of The Muscle | Yes / No |

| | |
|---|---|
| **1)Number Of Muscle Bellies Of Origin** | |
| **2) Origin Of The Muscle** | |
| Greater Trochanter | |
| Intertrochantric Line | |
| Lateral Lip Of Linea Aspera | |
| Any Other Origin | |
| **3) Length Of The Muscle Belly (cm)** | |
| **4) Breadth Of The Muscle Belly(cm)** | |
| **5) Width Of The Muscle Belly(cm)** | |
| **6)Volume Of The Muscle $(cm)^3$** | |
| **7)Shape Of The Muscle** | |
| **8)Aponeurosis Of The Muscle** | |
| Superficial | |
| Deep | |
| Length Of The Aponeurosis (cm) | |
| Breath Of The Aponeurosis(cm) | |
| **9)Distal Insertion** | |
| Merges With VastusLateralis | |
| Merges With VastusIntermedius | |
| Inserts independently | |
| **10)Blood Supply** | |
| Transverse Branch Of LCFA** | |
| Ascending Branch Of LCFA ** | |
| **11)Nerve Supply** | |
| Direct Branch From posterior Division Of Femoral Nerve | |
| Branch through nerve to vastus lateralis / Nerve to Vastus Intermedius | |

** - Lateral Circumflex Femoral Artery

**Radiological study**

| SERIAL NO | HOSPITAL NO | AGE | CLINICAL DIAGNOSIS | GENDER (MALE / FEMALE) | SIDE (RIGHT LEFT) | INCIDENCE OF THE ADDITIONAL MUSCLE HEAD | |
|---|---|---|---|---|---|---|---|
| | | | | | | OBSERVER 1 | OBSERVER 2 |
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