

ORIGINAL COMMUNICATION

A Newly Discovered Muscle: The Tensor of the Vastus Intermedius

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The quadriceps femoris is traditionally described as a muscle group composed of the rectus femoris and the three vasti. However, clinical experience and investigations of anatomical specimens are not consistent with the textbook description. We have found a second tensor-like muscle between the vastus lateralis (VL) and the vastus intermedius (VI), hereafter named the tensor VI (TVI). The aim of this study was to clarify whether this intervening muscle was a variation of the VL or the VI, or a separate head of the extensor apparatus. Twenty-six cadaveric lower limbs were investigated. The architecture of the quadriceps femoris was examined with special attention to innervation and vascularization patterns. All muscle components were traced from origin to insertion and their affiliations were determined. A TVI was found in all dissections. It was supplied by independent muscular and vascular branches of the femoral nerve and lateral circumflex femoral artery. Further distally, the TVI combined with an aponeurosis merging separately into the quadriceps tendon and inserting on the medial aspect of the patella. Four morphological types of TVI were distinguished: Independent-type (11/26), VI-type (6/26), VL-type (5/26), and Common-type (4/26). This study demonstrated that the quadriceps femoris is architecturally different from previous descriptions: there is an additional muscle belly between the VI and VL, which cannot be clearly assigned to the former or the latter. Distal exposure shows that this muscle belly becomes its own aponeurosis, which continues distally as part of the quadriceps tendon. Clin. Anat. 29:256–263, 2016. © 2016 Wiley Periodicals, Inc.

Key words: quadriceps femoris muscle group; quadriceps tendon; tensor vastus intermedius TVI; quinticeps; extensor apparatus of the knee joint

INTRODUCTION

The quadriceps femoris is traditionally described as a muscle composed of the rectus femoris and the three vasti, the lateralis, intermedius and medialis, which arise independently and blend into the common quadriceps tendon (Putz and Papst, 2008; Platzer et al., 2010; Schünke et al. 2014; Paternoster, 2012). However, clinical experience and anatomical studies do not confirm textbook descriptions of the vastus lateralis (VL) and intermedius (VI) muscles. After careful

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anatomical dissection of the muscle bellies we found an additional muscle between the VL and VI, hereafter named the tensor VI (TVI), which cannot be clearly assigned to the either of those muscles.

In a cadaver study, Golland et al. investigated the gross morphology of the VL with regard to fusion between adjacent muscles. They found a separate muscle belly arising from the anterior aspect of the upper femoral shaft in 29% of thighs (Golland et al., 1986). Another study revealed an additional fleshy lamella in the distal part between the VL and the VI in 36% (Willan et al., 1990).

Subdivision of the VL into various muscle bellies is logical in view of its innervation pattern. It is supplied by several muscle branches of the femoral nerve, which in turn can be divided into two parts (Patil et al., 2007; Becker et al., 2010). According to recently published anatomical observations, the proximal-ventral aspects of the bellies of the VL and VI are supplied by numerous muscle branches of the femoral nerve (F), and by branches of the lateral circumflex femoral artery and vein (LCFA and LCFV) (Grob et al., 2015). This creates the impression that the TVI belongs to the VL. However, distal anatomical exposure revealed that this muscle belly has a separate aponeurotic tendon, closely associated with the aponeurosis of the VI, which joins the quadriceps tendon distally.

The aim of the following anatomical study was to clarify, in terms of muscle innervation, whether the TVI was a variation of the VL or the VI, or a separate head of the extensor apparatus of the knee joint.

MATERIALS AND METHODS

Twenty-six lower limbs of 16 embalmed cadavers, nine males (six paired and three unpaired) and seven females (four paired and three unpaired), were investigated by macro-dissection. The bodies were obtained from the institutional body donation program (<http://www.anatom.uzh.ch/Bodydonation.html>) following the ethical guidelines "On the use of cadavers and parts of cadavers in medical research and for pre-, post-grad and continued education and research with human subjects" by the Academy of Medical Sciences (SAMS). All lower limbs were embalmed in a formalin-based solution. The limbs of four specimens were cut transversely in the middle third of the thigh after dissection. The thighs were examined using a standardized dissection protocol. Each lower limb was placed supine on a dissection table. The hip joint was approached from the anterior aspect. The ascending branch of the LCFA was identified and traced medially. Following resection of the joint capsule, the proximal margins of the muscle bellies of the VL and VI were located. The femoral nerve was located proximal to the inguinal ligament, then dissected and traced distally. All muscle branches of the femoral nerve to the sartorius and the rectus femoris were identified. For better access, these muscles were transected distally and lifted proximally. All muscle branches of the femoral nerve and all vessels to the quadriceps femoris were carefully dissected. The architecture of the quadriceps femoris was

examined to confirm its anatomy, with special attention to the innervation pattern. Additional muscle bellies were sought. All muscle bellies in the area of the VL and VI were traced from their origin to their insertion and their affiliations were determined. An MRI of the quadriceps femoris was also studied to confirm the anatomical findings. This is illustrated by a single case in this article.

RESULTS

In all dissections ($n = 26$), a separately innervated TVI muscle belly was found between the muscle fascias of the VL and the VI (Fig. 1). Further distally, the TVI combined into a broad and flat aponeurosis merging into one of the deep layers of the quadriceps tendon. In 22/26 cases, the TVI could be clearly separated in the proximal aspect from the muscle bellies of the VI and VL. In the remaining 4/26 cases, no clear proximal separation was possible.

All three muscles—the VL, the TVI, and the VI—presented a common, hardly-divisible origin between the intertrochanteric line and greater trochanter (Common-type) (Fig. 2). In 5/26, two or more smaller intervening muscle lamellae were also found (Fig. 2). Further distally, at the junction into the broad tendinous portion, the TVI was always adjacent to, and often integrated into, the aponeurosis of the VI. Covering the aponeurosis of the VI, the aponeurosis of the TVI reached the distal aspect of the quadriceps femoris. The aponeurosis of the VI could hardly be distinguished from that of the TVI at first glance (Figs. 3 and 4).

However, the tendon of the TVI could easily be separated from both the VI and VL in 42% ($n = 11$) (Independent-type); the aponeurosis of the TVI was inseparable from that of the VI in 23% ($n = 6$) (VI-type), and could be separated from the VI but not the VL in 19% ($n = 5$) (VL-type) (Fig. 2). In four paired specimens, where both sides were dissected, the TVI appeared identically on both sides of the body. In the remaining six paired specimens, different types of TVI were found on opposite sides. The aponeurosis of the TVI consistently changed its course; running laterally in the mid-third of the thigh, it moved ventrally shortly before its point of entry in the quadriceps tendon (Figs. 5 and 8). In the distal aspect, the three layers originating from the VI, the TVI, and the VL could be clearly isolated in all cases. The anatomical finding of the TVI muscle and its aponeurotic tendon was also confirmed in a MRI cross section (Figs. 6 and 7).

The pattern of quadriceps tendon layers toward the proximal muscular parts was always identical: the VI was the deepest layer, the TVI formed the deep portion of the middle layer, and the VL made up the superficial portion of the middle layer. The rectus femoris always formed the most superficial layer of the quadriceps tendon. The insertion of the TVI was at the medial aspect of the patellar base (Fig. 8). In three cases the distal aponeurosis of the TVI became narrow further distally (< 3 cm) and continued as a tendon-like structure laterally and dorsally in the

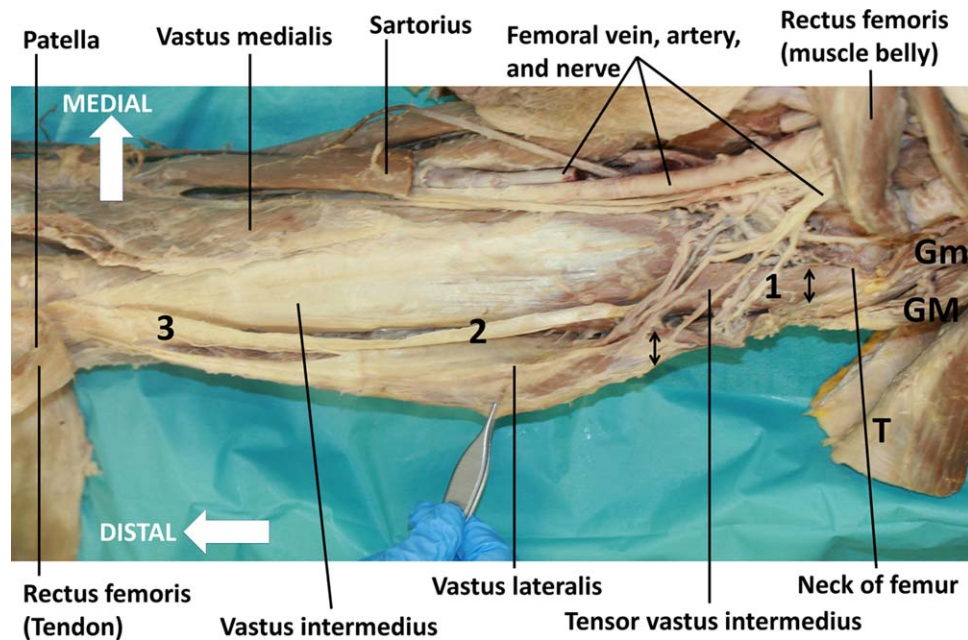


Fig. 1. Anterior overview of a left thigh showing the quadriceps femoris muscle. The rectus femoris, the Sartorius, and tensor fasciae latae (**T**) are transected and reflected on either side, proximally and distally. The capsule of the hip joint is removed presenting the neck of the femur. The TVI (**1**) can be seen between the muscle laminae of the VL and the VI. Further distally the TVI merged

into a broad aponeurosis (**2**) becoming a tendinous structure (**3**) at the level of the quadriceps tendon. GM, gluteus medius; Gm, gluteus minimus. The size of the TVI is very variable. In contrast to Figure 9, the muscle belly of the TVI in this specimen is proximally larger than that of the VL (black arrows). The origin of the TVI is more proximal than that of the VL.

intermuscular septum. In one case this tendon ended in the broad aponeurosis of the VI, which was itself divided in the distal aspect. Instead of the TVI, the lateral portion of the VI aponeurosis merged into the middle layer of the quadriceps tendon.

At the site of origin of the TVI, the anterior aspect of the greater trochanter, fibers of the TVI spread into the insertion of the gluteus minimus (Fig. 1). From the dorsal aspect, the TVI always originated together with the VL and the VI (i.e., at the lateral lip of the linea aspera). The TVI was very variable in size (Figs. 1 and 9).

Nerve branches to the VL, TVI, and lateral portions of the VI originated from the same lateral deep division of the femoral nerve (Fig. 9). The VL, TVI, and VI could be divided only after the neurovascular structures were carefully traced. The TVI was always innervated proximally by multiple short branches in a very constricted space. However, in the deeper aspect, all the muscle branches supplying the TVI had terminal ramifications to the lateral portions of the VI. The TVI was vascularized separately from the VL through individual branches of the transverse branches of the LCFA and side branches of the ascending branch of the LCFA.

DISCUSSION

The quadriceps femoris is one of the most extensively-studied muscle groups in the human body. There have been many clinical, anatomical, and

biomechanical accounts of this muscle in recent years (Zeiss et al., 1992; Shelburne and Pandey, 1997; Willan et al., 2002; Blemker and Delp, 2006; Waligora et al., 2009; Pasta et al., 2010; Becker et al., 2010). Despite numerous descriptions in the literature, an intermediate muscle between the VL and the VI has been given little attention thus far (Testut, 1884; Le Double, 1897; Willan et al., 2002; Pabst, 2008; Moore et al., 2014;). There could be several reasons for this.

1. The muscle bellies of the VL, the TVI, and the VI are very close to each other in the proximal thigh and are covered with a complex network of vessels and nerves.
2. The TVI originates at a site rarely seen in surgical routine. Therefore, the surgeon remains unaware of the specific anatomical features of this region.
3. Further proximally, the TVI continues into an aponeurosis that is very close to the VI but is then separate at the level of the quadriceps tendon. Thus, in a cross-section of the thigh, the aponeurosis of the TVI is not seen as a muscle but merely as a fascial layer or an intermuscular septum. However, knowing that the TVI exists, one can distinguish an aponeurotic sheet between the medial aponeurosis of the VL and the lateral aponeurosis of the VI (Figs. 6 and 7).
4. The morphology of the TVI differs among individuals (Fig. 2).

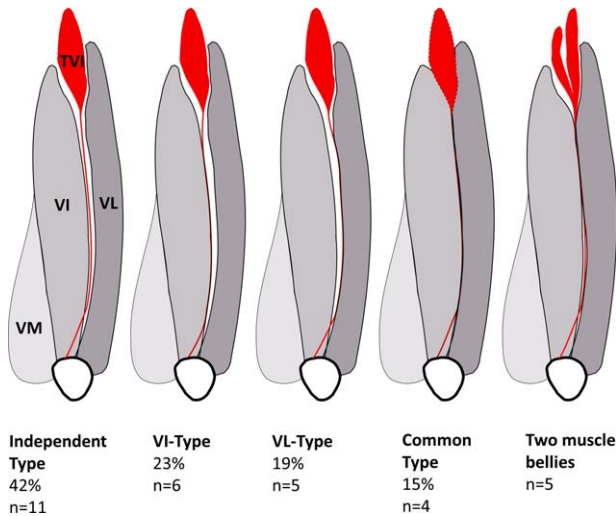


Fig. 2. The schematic drawings show the different types of the TVI and its variations with respect to interactions with the VI and VL. In 42%, the aponeurosis and muscle belly of the TVI could be clearly distinguished from the aponeuroses of VI and VL (Independent-type, see also Fig. 1). In 23% ($n = 6$), the aponeurosis of the TVI passed inseparably into the aponeurosis of the VI (VI-type) and in 19% ($n = 5$), it could be separated from the VI but not from the VL (VL-type). In 15%, the VL, TVI, and VI presented a common, hardly-divisible origin between the intertrochanteric line and the greater trochanter (Common-type). In five cases there were two or more smaller intervening muscle lamellae of the TVI.

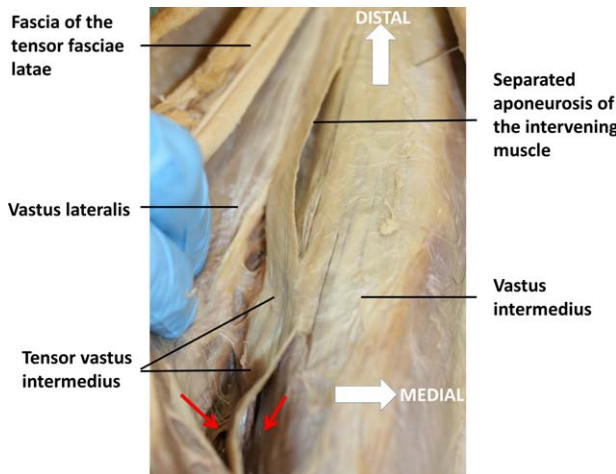


Fig. 3. Antero-lateral view of the middle two-thirds of the left thigh. The rectus femoris is reflected and not visible. The TVI lamella can be seen between the VL and VI. The TVI merges into a broad aponeurosis that runs adjacent to the VI (see also Fig. 6). To some extent the aponeurosis of the TVI is separate from the aponeuroses of the VI and VL. In the dorsal aspect of the thigh the three muscles—VL, TVI, and VI—join (red arrows) and have a common origin at the lateral lip of the linea aspera of the femur.

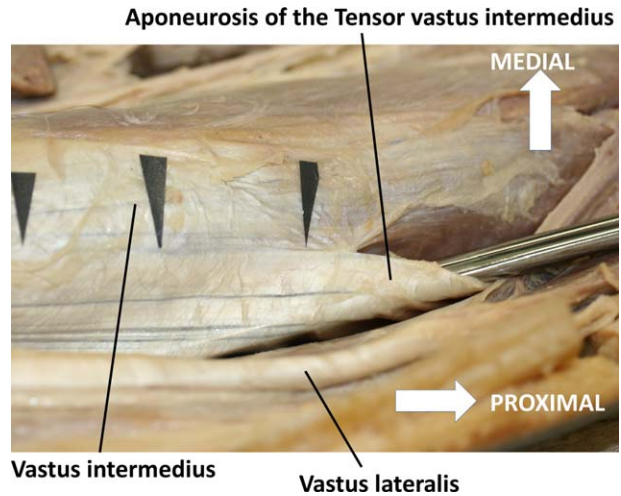


Fig. 4. Lateral view of the middle section of the left quadriceps femoris muscle. The rectus femoris is reflected and, therefore, not visible. The aponeurosis of the TVI runs adjacent to the VI and is hardly visible at first glance. The black arrows indicate the border between the aponeuroses of the VI and the TVI. Proximally (scissors) the aponeurosis of the TVI is separated from those of the VI and VL.

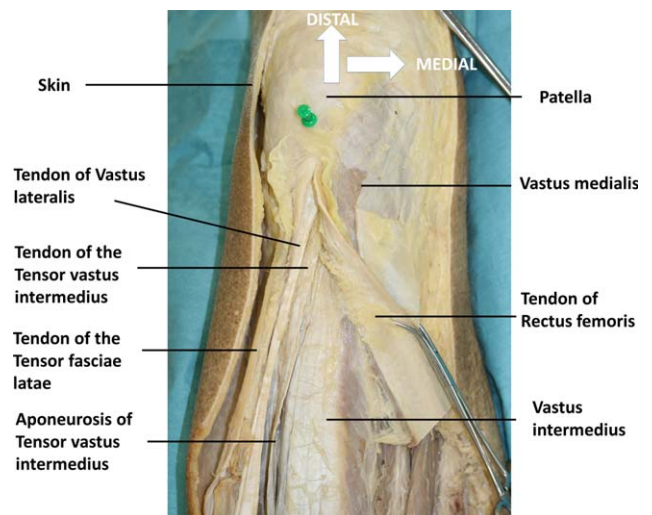


Fig. 5. Anterior view of a distal left thigh. The rectus femoris is transected. The distal part of the rectus femoris tendon is reflected medially. The proximal part of the rectus femoris is reflected proximally and, therefore, not visible. The separated aponeurosis of the TVI, and further distally its tendon, can be seen between the tendons of the VL and VI. The tendon of the TVI merges into the quadriceps tendon together with the tendons of the VI, VL, VM, and rectus femoris. The green pin indicates the insertion of the quadriceps tendon at the patella. In the dorsal aspect of the thigh the three muscles—VL, TVI, and VI—join and have a common origin at the lateral lip of the linea aspera of the femur.

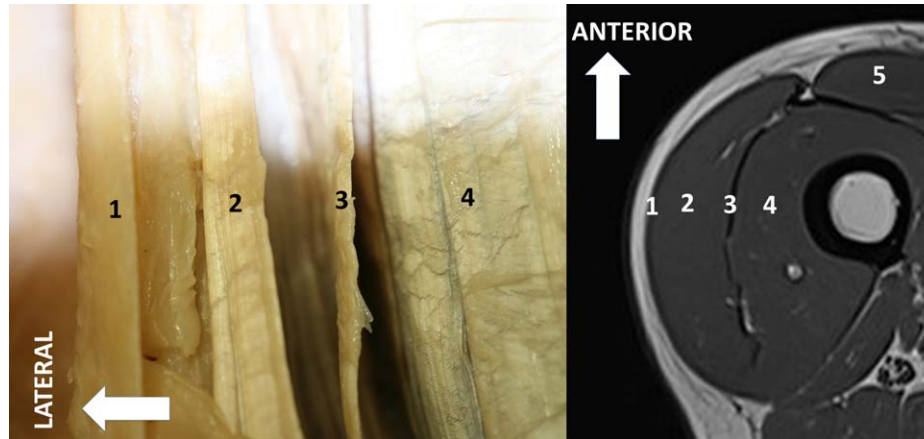


Fig. 6. (a) Small section of the lateral quadriceps femoris muscle. The rectus femoris is removed. The various aponeurotic layers of the lateral thigh are shown. **1:** tensor fasciae latae, **2:** VL, **3:** TVI, and **4:** VI. (b) MRI cross-section through the femur in the middle third (not the same specimen as in a). The intermuscular septum between **2** (VL) and **4** (VI) corresponds to **3** (TVI). **5:** rectus femoris.

To our knowledge, the TVI has not been described or illustrated in any textbook of anatomy. The VL is generally shown as a muscle with a single belly, separated from the VI by a intermuscular septum (Pabst, 2008; Platzer et al., 2010; Schünke et al., 2014; Moore et al., 2014). However, some authors have reported variable fusion between the VL and the adjacent musculature (Henle, 1880; Krause, 1880; Le Double, 1897). Golland et al. found a separate muscle belly of the VL arising from the anterior aspect of the

upper femoral shaft in 29% of dissected thighs (Golland et al., 1986). They reported that the belly usually contributes to a tendinous lamina distally, but occasionally fuses with the VI. In another cadaver study, Willan et al. found consistent results (Willan et al., 1990) among 40 cadavers, reporting an additional muscle lamina between the VL and the VI in 36%. Two muscle bellies of the VL have also been reported by other authors (Krause, 1880; Testut, 1884; Dwight, 1887; Holyoke, 1987).

Henle described the VL as a multi-layered muscle with superficial and deep portions (Henle, 1880). The

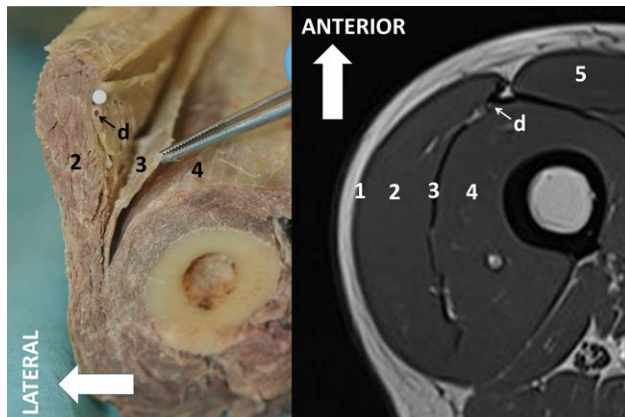


Fig. 7. (a) Anatomical cross-section through the left thigh. The skin and tendon of the tensor fasciae latae have been removed. The rectus femoris reflected medially and visible. **2:** VL, **3:** TVI, **4:** VI. The descending branch of the lateral circumflex femoral artery (**d**) runs through separate fatty connective tissue (pinned and marked with a white arrow). (b) MRI cross-section through the femur in the middle third (not the same specimen as in a). The intermuscular septum between **2** (VL) and **4** (VI) corresponds to **3** (TVI). **5:** rectus femoris; **d:** descending branch of the lateral circumflex femoral artery.

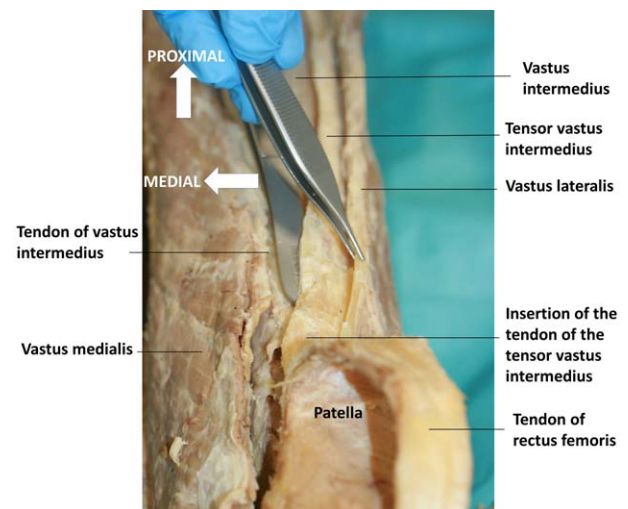


Fig. 8. Insertions of the rectus femoris, VL, TVI, and VI into the patella. The tendon of the rectus femoris is reflected distally over the patella. Both the TVI and the VL are parts of the middle layer of the quadriceps tendon. The TVI inserts at the medial aspect of the patellar base. The VM is detached from its insertion at the patella.

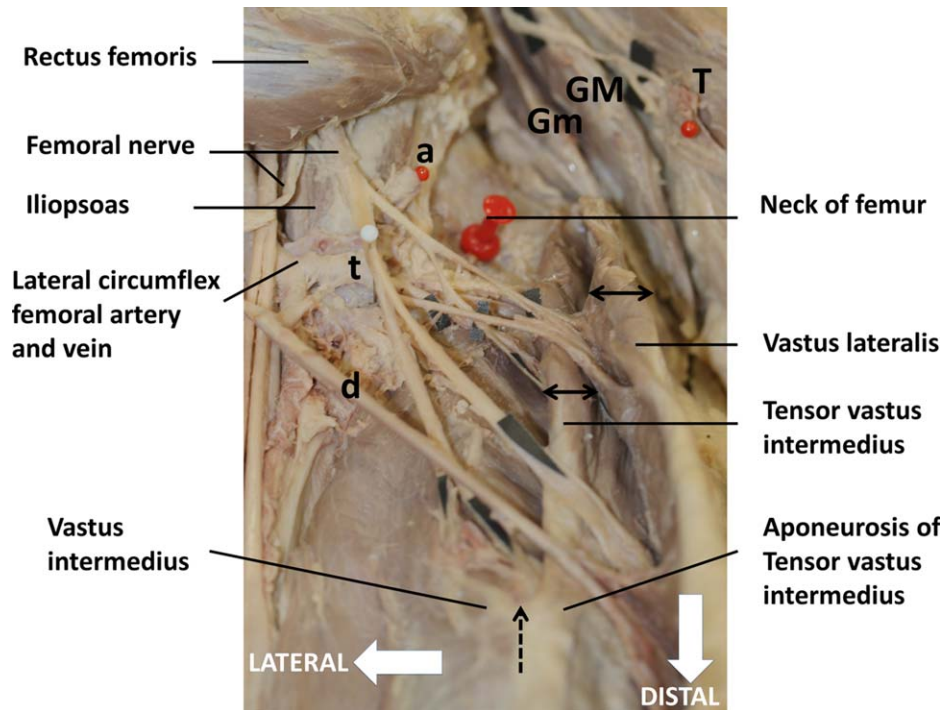


Fig. 9. Antero-lateral view of the left hip joint. The joint capsule is removed and the neck of the femur (large red pin) is visible. The transected rectus femoris is held medially. The proximal aspects of the VL, the TVI, and the VI are shown. The TVI lamella lies between the muscle lamellae of the VL and VI. All these muscles are innervated by branches of the same lateral division of the femoral nerve. In order to visualize the nerve branches better, the terminal branches of the lateral circumflex femoral artery and vein are transected (**a**, **t**, and **d**:

ascending, transverse and descending branches). Gm gluteus minimus, GM gluteus medius, T Tensor fasciae latae. The size of the TVI is very variable. In contrast to Figure 1, the muscle belly of the TVI in this specimen is comparable in size to that of the VL (black arrows). The origin of the TVI is located at the same level (at the greater trochanter) as that of the VL. The TVI merges into a broad aponeurosis that runs adjacent to the VI (see also Fig. 3). The blue arrow indicates the point where the TVI becomes adjacent to the VI.

regular occurrence of two neurovascular sources, as described for the VL, also suggests more than one muscle belly (Frohse and Fränkel, 1913; Patil et al., 2007; Becker et al., 2010). Becker and coworkers described the VL as a muscle consisting of four distinct anatomical partitions, named the central, superficial proximal, deep proximal and deep distal portions. In seven of 10 specimens, partitioning was enhanced by an areolar fascial plane between the central and the deep distal partitions (Becker et al., 2010). Labbé reported a symptomatic, progressive restriction of the knee joint in a 9-year-old girl due to an accessory VI. Its tendon and muscle belly were completely separated from the other components of the extensor apparatus (Labbé et al., 2011). Yet other authors have referred to complex fusion between the VL and the VI (Engstrom et al., 1991; Willan et al., 2002; Becker et al., 2009). Frohse and coworkers did not distinguish between the VL and VI, suggesting instead that the extensor apparatus of the knee consists of only three muscle heads (M. triceps femoris) (Frohse and Fränkel, 1913). Despite these anatomical findings, the possibility of a separate intermediate muscle arising proximally between the bellies of the

VL and the VI and inserting separately at the medial aspect of the patellar base has not previously been explored.

The deep parts of the quadriceps femoris do not vary much among individuals. However, besides the bilaminar structure of the vasti, Bergman and coworkers mention that a slip (rectus accessorius) can arise from a tendon at the edge of the acetabulum and insert into the ventral edge of the VL (Bergman, 2015). Bergman et al. refer to Grubers' observations between 1856 and 1866 concerning a rectus femoris accessorius found in three specimens. In all three, the rectus femoris accessorius arose with a long tendon lateral to the main rectus femoris origin from the anterior inferior iliac spine and inserted into the fleshy vastus externus (VL) (Gruber, 1888). This was not observed in the present study. The TVI always originated at the anterior aspect of the greater trochanter distal to the intertrochanteric line.

In contrast to previous studies, we found at least one additional muscle belly between the VL and the VI. In many cases, the individual muscle bellies could be distinguished only after the neurovascular structures were traced. The supply to the VL was clearly

delineated, in contrast to the TVI and the VI. The main part of the VL was consistently supplied by muscular branches that ran together with the descending branch of the LCFA. In contrast, the neurovascular supply to the TVI consisted of shorter proximal femoral nerve branches and vessels of the transverse or ascending branch of the LCFA. The same neurovascular structures also supplied lateral portions of the VI, which confirms that the TVI cannot be clearly assigned to the VL.

Over the years, anatomical dissections of the quadriceps femoris have mainly focused on the special features of the extensor apparatus in the distal region (Hollinshead, 1969; Zeiss et al., 1992; Hubbard et al., 1997; Andrikoula et al., 2006; Waligora et al., 2009). It has been suggested that the VL is composed of two parts: VL obliquus (VLO) and VL longus (VLL) (Hallisey et al., 1987). These inferences were based on the pennation angles of the superficial fascicles only. No differences in respect of innervation pattern or blood supply have been reported. The VLO and VLL were not separately innervated.

Many authors have tried to decipher the architecture of the quadriceps tendon (Hollinshead, 1969; Fulkerson, 2004; Waligora et al., 2009). In this regard, the TVI should be considered a separate muscle belly. This study has demonstrated that it has its own layer in the middle layer of the quadriceps tendon. The muscle portions of the quadriceps femoris are arranged distally such that the individual layers come together and lie above each other like the layers of an onion. In the proximal two thirds of the muscle group the external and internal layers lie adjacent to each other. However, at the level of the quadriceps tendon, the external layers lie above the inner ones. This explains why the quadriceps tendon is described as many-layered when observed in transverse section (Zeiss et al., 1992; Waligora et al., 2009).

In view of its course from the anterolateral aspect of the greater trochanter to the medial base of the patella, the TVI appears to be significant in controlling the motion of the patella. Its fibers entering the middle layer of the quadriceps tendon from the oblique lateral aspect counteract the forces of the medial fibers of the VM. The steering function of this muscle is also suggested by its rich innervation.

Alternatively, since the aponeurosis of the TVI is in close contact or fused with that of the VI over a long distance, the TVI appears to exert tension on the VI aponeurosis and medialize the action of the VI. Hence, the TVI seems to be a type of "tensor of the VI." In contrast to the tensor fasciae latae, it is fixed to the corresponding medial muscle layer (Figs. 3 and 10).

In our opinion the TVI fulfils all criteria for an independent muscle. It is innervated by independent branches of the femoral nerve and is vascularized through separate muscle branches. Furthermore, it has a defined origin at the anterior aspect of the greater trochanter and inserts in the middle layer of the quadriceps tendon at the medial patellar base. Despite its variable connections with the adjacent muscles in the proximal aspect of the thigh, the TVI, VL, and VI can always be clearly distinguished in the distal aspect.

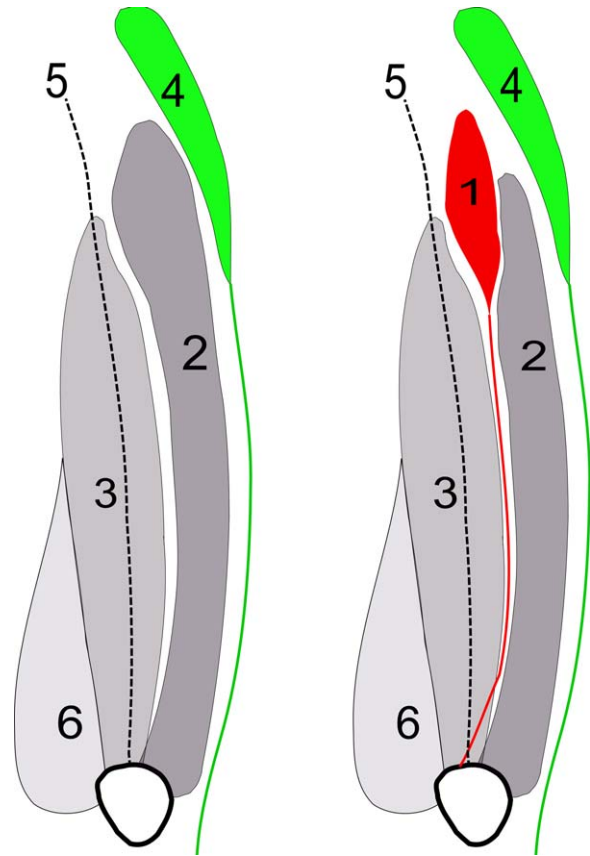


Fig. 10. Schematic drawings of the quadriceps femoris muscle and the tensor fasciae latae (green). **(a)** As described traditionally in anatomy textbooks: **2:** VL, **3:** VI, **4:** tensor fasciae latae, **5:** rectus femoris (dotted line), **6:** vastus medialis, **P:** patella. **(b)** According to this study, an additional TVI (**1**, red) can be found between the VL and VI. This muscle could act as a second tensor (in addition to the tensor fasciae latae).

To date, the TVI has been attributed to the VL. Indeed, the affiliation of the TVI to the VL is confirmed by the close relationship of the two muscle heads in the proximal aspect. However, the course and function of the TVI and its neurovascular supply suggest that it is aligned more with the VI than the VL. Yet, when the nerves supplying the quadriceps femoris are viewed as a whole, the TVI should be considered together with the VL and the lateral portion of the VI as a functional unit. All three lamellar muscles are closely related and are supplied by the same deep lateral division of the femoral nerve.

The morphology of the TVI shows intra- and inter-individual differences. There are individual variations in respect of the degree of fusion between the muscle bellies of the VL and the VI (Willan et al., 2002). These connections are also found between the layers of the VI and the TVI, as well as the TVI and the VL. On the basis of this study it is not clear whether physical exercise or pathological conditions are implicated in these individual differences.

Interpreting the TVI as an independent muscle and understanding its role within the extensor mechanism would change our understanding of the complex architecture and function of the extensor apparatus of the knee joint as a whole. The present anatomical description is by no means a comprehensive report on the TVI. Further work should combine these anatomical findings with advanced imaging techniques. If the muscle bellies of the quadriceps could be distinguished by modern imaging procedures, exercise- or disease-related differences between the individual muscles could be identified.

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