Triceps, quadriceps or pentaceps femoris? Need for proper muscle definition

Triceps, quadriceps ou pentaceps femoral, ou la nécessité d'une définition musculaire précise.

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Résumé:

Introduction : Au cours des dernières années, la définition du quadriceps fémoral (QF) a quelque peu évolué et certains auteurs définissent maintenant une cinquième chef : le tenseur du vaste intermédiaire (TVI). Les descriptions des différents composants QF dans les manuels d'Anatomie et les résultats récemment publiés sont contradictoires. L'objectif de cette étude est donc d'obtenir plus d'informations sur ce potentiel chef supplémentaire.

Matériels et méthodes : Vingt membres inférieurs de 10 cadavres embaumés, six femmes et quatre hommes, ont été examinés par macro-dissection. La dissection et la séparation des différents chefs ont été effectuées avec les doigts et une distinction entre les différentes parties du quadriceps n'a été notée que s'il était possible de séparer les têtes sans scalpel pour éviter une séparation artificielle des parties musculaires.

Résultats : Dans 9 membres inférieurs, nous avons trouvé une QF tel que décrit classiquement dans les manuels. Le TVI n'a été trouvé que dans 7 membres et dans 4 cas, nous n'avons pas pu différencier VI et VM ou VI et VL (triceps fémoral tel que décrit par Testut). Ces résultats et la diversité des descriptions que l'on trouve dans la littérature nous ont amené à revoir la définition d'un muscle, ou chef musculaire isolé.

Conclusion : Dans cette étude, la présence de TVI n'a pas été démontrée dans tous les membres, contrairement aux études publiées précédemment sur le sujet. L'harmonisation des techniques de dissection mais aussi une définition claire d'un muscle est nécessaire pour pouvoir comparer les études et tirer des conclusions claires.

Mots-clés

Quadriceps fémoral, appareil extenseur du genou, tenseur du vaste intermédiaire.

Abstract

Introduction: Over the last years, the definition of quadriceps femoris (QF) has evolved somewhat and some authors now define a fifth head: the tensor of vastus intermedius (TVI). Descriptions of the different components of QF in textbooks and recent findings remain confusing. Therefore, the aim of this study is to obtain more information on this possible fifth head.

Materials and methods: Twenty lower limbs of 10 embalmed cadavers, six females and four males, were investigated by macro-dissection. The dissection and separation of the different heads were performed with the fingers and a distinction between the different parts of the quadriceps was noted only if it was possible to separate the heads without scalpel to avoid artificial separation of muscle parts.

Results: In 9 lower limbs we found a QF as classically described in textbook. TVI was found in only 7 limbs and in 4 cases we were not able to differentiate VI and VM or VI and VL (triceps femoris as described by Testut). These results, and the diversity of descriptions found in the literature have led us to review the definition of an isolated muscle.

Conclusion: In this study, the presence of TVI was not demonstrated in all limbs unlike previously published studies on the subject. Harmonisation of dissection techniques but also a clear definition of a muscle is required in order to be able to compare studies and draw clear conclusions.

Keywords

Quadriceps femoris; extensor apparatus of the knee joint; tensor vastus intermedius

INTRODUCTION

The quadriceps femoris (QF) is, by definition, described as a muscle composed by four components; the rectus femoris (RF) and three vasti – the vastus medialis (VM), the vastus intermedius (VI) and the vastus lateralis (VL) [1]. These four parts end together into the common quadriceps tendon on the patella and continue by the patellar tendon onto the tibial tuberosity. A recent anatomical study revealed the existence of a fifth component of the quadriceps named the tensor of vastus intermedius (TVI) located between the VL and the VI, this muscle was present in all the dissected thigh (n = 26) [2]. The same author continued the description of this new muscle and found that it can be even be separated into the different layers of the quadriceps tendon [3]. The authors described the 6 following layers in the tendon: 1. lateral aponeurosis of the VI, 2. deep and 3. superficial medial aponeurosis of the VI, 4. VL, 5. TVI and 6 the RF. Another study extensively analysed this muscle, they also found it in every case (n = 36) [4]. These authors made a more precise description of the TVI, especially the origins. Four types of TVI have been defined [2],[4]:

Type 1 (independent): the muscle takes origin from the upper part of the intertrochantric line and anterior part of greater trochanter but the origin is separable from VL origin (33.33%). The aponeurosis is separable from both VI and VL.

Type 2 (VI type): the muscle takes origin together with VI and the posterior border of TVI is fused with VI (8.33%). The aponeurosis is separable from VL.

Type 3 (VL type): the muscle takes origin from the VL and the origin is inseparable (30.56%). The aponeurosis is separable from VI.

Type 4 (common): the muscle takes origin from the VL and the origin is inseparable (27.78%). The aponeurosis is separable from both VL and VI.

Schematic representations of those 4 types of TVI are presented in Figure 1.

TVI has also been highlighted using medical imaging: ultrasonography [5] and magnetic resonance [6].

The results of these studies (i.e. the presence of the TVI in all of the 52 dissected lower limbs) can be surprising if we considered the classical description, generally well admitted since centuries, of this muscle. In this perspective, it may be interesting to look at the variations in insertions of the different vasti areas constituting the quadriceps. In a recent study the authors analyzed the origins of the different vasti using isolated muscles [7]. 33 QFs were dissected and the authors found that the origins of VM and VL were constant but that VI was much more structurally diverse. In typical cases (23 of 33), VI attached directly to the anterior and lateral surface of the femoral shaft. It adjoined the origin of VL at the lateral lip of the linea aspera to form a common origin. In some cases (10 of 33), the muscle belly and origin of VI were much smaller than those in the typical cases; VI attached only to the anterior surface of the femur and did not contact the lateral lip. In addition, the muscle belly of VI was narrow and almost corresponded to the width of the femoral shaft [7].

While the actual trend is to add a supplementary muscle in the quadriceps it is interesting to take a look back in historical descriptions.

In 1875 Macalister in his *Observations on muscular anomalies in the human anatomy* made the following description *"The relation of this muscle (VL) to the rest of the extensor is variable; sometimes at its insertion it is inseparable from the VI, at other times we saw the two vasti uniting over the tendon of this muscle, thus forming a canal in which the rectus tendon ran to its insertion; or the VL may be inserted into the outer border of its tendon, while the VM and VI lie beneath"*[8].

In 1884 Testut in his textbook *Les anomalies musculaires chez l'homme, expliquées par l'anatomie comparée et leur importance en anthropologie* refuted the classical definition of the quadriceps and described a *triceps crural (femoris)* composed by the RF, VM and the VL

[9]. According to Testut it is not possible to differentiate the VI and the VM, they are one unique entity. Le Double made the same observation in 1897.

In 1913 Frohse & Fränkel in the textbook *Handbuch der Anatomie des Menschen* also described a *triceps femoris* with a fusion of the VI and the VM as presented in Figure 2 [10].

Several factors can explain, partially, the evolution of the description of the quadriceps from triceps to pentaceps femoris: the improvement of the conservation and dissection techniques and the improvement of imaging (TVI has been described on MRI by Grob [2]).

One issue that has not been investigated yet concerning the TVI is the organogenesis of this muscle.

Concerning the development of this muscle little is known about the organogenesis. From the embryological point of view, we have not found any information in the literature on the development specific to the vasti of the extensor apparatus.

With regard to comparative anatomy, we also found no interesting example to explain these variations in humans.

The QF plays an important role in human movement and in the clinics. Knee extension force is one of the predictors of knee osteoarthritis and is therefore important to assess. In this context a group of researchers suggested that among the four muscles that make up the QF, the muscle architecture of VI is the best predictor of knee extension force [11]. Careful attention must therefore be paid to the VI and the potential presence of TVI.

The aim of this dissection study was to determine if the presence of TVI in all dissected specimens was verified, or if previous classical descriptions of a quadriceps with three separated vasti or a the triceps femoris as described by Testut (1884) [9], Frohse & Frankel (1913) [10] should be considered.

MATERIAL AND METHODS

Twenty lower limbs of 10 embalmed cadavers, six females and four males, were investigated by macro-dissection. The number of specimens dissected was based on a previous study about sample size considerations in human muscle architecture [12].

The bodies were obtained from the institutional body donation program (https://www.erasme.ulb.ac.be/fr/enseignement-recherche/don-du-corps-a-la-science) following ethical guidelines. The bodies were prepared using the modified Dankmeyer method (for 1 liter H_20: 50 ml alcohol (95%), 50 ml Formol (40°), 10 g phenol, 20 g glycerin, 50 g Chloral Hydrate, 12.5 g $NASO_4$, 12.5 g $MgSO_4$, 25 g KNO_3) , and preserved in water containing 2% phenol . The following standardized protocol was used to perform the dissection. Cadavers were placed in supine position on the dissection table. Three skin incisions were performed: from anterior superior iliac spine to pubic tubercle, a horizontal incision below the tibial tuberosity and a vertical incision between these two incisions. The sartorius then the rectus femoris were transected distally and lifted proximally to allow dissection of the deep parts of the quadriceps. Particular attention was paid to the innervation of the muscle. The different branches of the femoral nerves were carefully dissected from proximal (inguinal ligament) to the different vasti. The dissection and separation of the different heads were performed with the fingers and a distinction between the different parts of the quadriceps was noted only if it was possible to separate the different heads without scalpel to avoid artificial separation of muscle parts.

A cross section of the thigh of a near-term foetus, from the collection of the Anatomy museum of Université Libre de Bruxelles, embedded in Canada balm were observed and photographed. This piece and a cross section of the thigh of an adult are presented in Figure 3.

RESULTS

Results, observations and description of the twenty lower limbs are presented in Table 1. A summary of the finding is presented in Figure 4 and dissection of TVI in Figure 5.

When present (n = 7), the TVI had a common origin with VL in 86% of the case. Considering the laterality, we found in 15% of cases a unilateral pentaceps and in 20% of cases the TVI was present in both lower limbs.

Concerning the symmetry, we found the same muscle composition in 6 bodies out of 10 (1 bilateral triceps, 3 bilateral quadriceps and 2 bilateral pentaceps). For the 4 asymmetric cases the composition was as follows: in 2 bodies we found one pentaceps and one quadriceps, in 1 body one pentaceps and one triceps and in 1 body one quadriceps and one triceps.

No difference was found between male and female (at least one TVI in 50% of the cases for both gender). The innervation displayed large variability; the different cases are presented in Table 1.

DISCUSSION

Due to the major role that it plays in gait and posture but also in pathology (e.g. patellofemoral pain syndrome) the quadriceps femoris is one of the most studied muscle groups of the human body. Therefore, the fact that very recently, a new muscle head was described in 2016 is more likely due to a definition issue than a problem with the dissection protocol, the interpretation of medical imaging or a phylogenetic evolution. Historically the quadriceps was described with four or three muscle heads according to the different authors. In recent years, several studies have extensively investigated the different components of the quadriceps (vasti and tendons).

Concerning the RF, the classical descriptions of the origin, innervation and vascularization are well admitted but there are still questions about the tendon. For some authors the RF tendon inserts on the tibial tuberosity accompanied by the patellar tendon [1], others described a fusion of the RF and remaining quadriceps tendon [3][14]-[15].

The current discussion is about the vasti and their distinction. The VM is composed of two parts: the VM obliquus (VMo) and the VM longus [16]. The VMo runs from the tendon of adductor magnus to the medial and superior part of the patella [17]. Due to the orientation of muscle fibers this muscle is one of the key elements for centring the patella and avoiding patellofemoral pain syndrome [18]-[21]. There is, currently, no discussion about the VI running from the anterior part of the femoral diaphysis (2/3 superior) to the quadriceps tendon. Interestingly more work concerns the VL. As for VM, VL is composed by two parts: the VL obliquus and the VL longus, these two parts receive separated innervation [22] and fuse in a common tendon [23]. Based on muscle architecture and innervation, Becker et al. (2010) described four different parts of the VL [23].

The fact that several parts of the VL have already been described based on macro-dissection and innervation and that a new muscle head located between VI and VL has been discovered leads to the following question: what is the definition of a proper muscle?

Concerning the origins, should they be clearly separate? In their study, Veeramani & Gnanasekaran in 2017 found that the origin of the TVI was on the upper part of intertrochanteric line and greater trochanter only in the independent type of TVI (33.33%). In all other types, the origin of TVI was either together with VL or together with VI. Therefore, with regard to this question, the answer is no.

Another question is to know if a separate muscle must be included in a specific fascia. Recent research has provided major advances in the definition and the role of fascia. There has been renewed interest in recent years on the importance of fascia and supporting tissues in biomechanics and pathology [24]-[25] but it is difficult to obtain precise definitions and distinctions of these tissues [26].

Another important point is the innervation: should a separate muscle receive independent innervation? Previous descriptions of the TVI [2][4] and results of this study found a proper

innervation for the TVI, but several muscles also receive multiple nerve branches (e.g. adductor magnus). Therefore, the answer to this question is no. The same question and answer can be raised for blood supply.

From the functional point of view, the action of a muscle, or part of a muscle, must be considered. This is complex question. In most cases, muscles composed by several heads are bi-articular. The action on the distal joint is therefore the same but the action of the proximal joint crossed may differ. As studies concerning TVI are recent, there is, currently, no study about its role or its implication in pathology. The VI was identified as the most important muscle for knee extension, therefore the TVI muscle could play a significant role in knee extension and patellar alignment, which can be crucial in isolated traumatic injury to its aponeurosis or the muscle [4]. Some authors also suggested that given its path and orientation, parallel to the tensor of the fascia lata, it could act in synergy with it. Therefore the answer is probably no.

Concerning the functional aspects another way to approach this problem would be to consider not the number of heads but the cross-section area (CSA) of this muscle. This issue is intensively studied in clinics as it remains unclear what role reduced volume and CSA of individual quadriceps muscles may play in persistent quadriceps weakness and more global dysfunction following anterior cruciate ligament reconstruction [27]. It has been shown that the atrophy of the VI and VM muscles negatively impacts knee extension strength following anterior cruciate ligament reconstruction. Another study investigated the volume asymmetry of the quadriceps muscle in a healthy population [28]. The authors found individual muscle asymmetry of 11-13% for the vasti which suggests that relatively large differences may exist between the two sides without having pathological implications. This asymmetry could be compared with the observations that we made, i.e. the same kind of muscles definitions in 6 bodies out of 10.

We have already mentioned that data concerning the embryology of the TVI are lacking. However, an interesting question is to know whether a muscle must have a specific embryological origin. If we consider the supraspinatus and infraspinatus [29], the answer is also no.

The last point that we need to address is the composition of this muscle or muscle head: real muscle or aponeurosis? Figure 3 illustrates cross-section of a human embryo where TVI can be observed as an aponeurosis between VI and VL. Another possibility to investigate this muscle is medical imaging. On MRI the aspect of the TVI is closer to the fascia lata than to VL [6]. These observations suggest that it would be more of an aponeurosis between the two muscles than a separate head. Moreover Willan et al. (1990, 2002) were the first to report an additional muscle lamina between the tendon of VL and VI in 36% of 40 cadavers [30][31]. This term of muscle lamina is probably more appropriate than muscle in this case.

The definition of a muscle and the different heads that make it up remains an open and actual question in anatomy due to the development of imaging and dissection techniques. In this context, it is important to find a general definition that takes into account morphological and functional aspects

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CONFLICT OF INTEREST

None declared.

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FIGURES CAPTIONS

Figure 1: Schematic representation of the different types of TVI as described by Grob et al. [29].

Figure 2: Example of a triceps femoris as described by Frohse & Fränkel (1913) where the vasti intermedius and lateralis are fused (2), (1) RF and (3) Fascia lata

Figure 3: A. Cross-section of a near-term foetus, B. cross-section of an adult. (1) RF, (2) VI, (3) VL and (4) TVI

Figure 4: Number of muscle heads contributing to the "quadriceps"

Figure 5: Dissection of the TVI. (1) VM, (2) VI, (3) VL, (4) muscle belly of TVI, (5) tendon of TVI, (6) femoral nerve

Table 1: Observation and description of the 20 dissected quadriceps, the different types of TVI are presented in Figure 1.

Subject	Right side			Left side		
	Muscles	Innervation	Comments	Muscles	Innervation	Comments
♂	Pentaceps	TVI : 2 VL : 2 VI : 2	Common origin for TVI and VL (Type 3)	Pentaceps	TVI : 1 VL : 2 VI : 1	Independent origins (Type 1)
♀	Quadriceps	VL : 2 VI : 1	/	Quadriceps	VL : 1 VI :1	/
♂	Pentaceps	TVI : 1 VL : 1 VI :2	Common origin for TVI and VL (Type 3). Clear distinction of tendons, the TVI is between VI (proximally) and VL (distally)	Quadriceps	VL : 2 VI : 2	/
♀	Pentaceps	TVI : 1 VL : 1 VI : 3	Common origin for TVI and VL (Type 3).	Triceps	VL : 3 VI+ VM : 4	Fusion between VI and VL that are contained in the same fascia
♀	Triceps	VL : 1 VI+ VM : 2	Fusion between VI and VL that are contained in the same aponeurosis	Triceps	VL : 1 VI+ VM : 2	Fusion between VI and VL that are contained in the same fascia. The VL is directly in the continuity

						of gluteus minimus.
♀	Pentaceps	TVI : 1 VL : 3 VI : 1	Common origin for TVI and VL (Type 3). Clear distinction of tendons the TVI is between VI (proximally) and VL (distally)	Pentaceps	TVI : 1 VL : 2 VI : 1	Common origin for TVI and VL (Type 3). No distinction of tendons
♂	Triceps	VL : 2	Fusion between VM and VI, the VL is split	Quadriceps	VL : 2 VI : 2	Fusion between VM and VI
♀	Pentaceps	TVI : 1 VL : 1 VI : 3	Common origin for TVI and VL (Type 3). Clear distinction of tendons, the TVI is between VI (proximally) and VL (distally)	Quadriceps	VL : 3 VI : 2	Voluminous aponeurosis between VI and VL
♀	Quadriceps	VL : 2 VM : 2	Innervation of VI is provided by a branch coming from VM	Quadriceps	VL : 3 VI : 2	/
♂	Quadriceps	VL : 2 VI : 3	Split of VL, one nerve for each part	Quadriceps	VL : 3 VI : 2	/