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Authors: Pedro Angullo-Gómez, Cristina Jiménez-Luna, Gloria Perazzoli, Jose Prados, Raul Ortiz, Laura Cabeza

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Quadriceps femoris muscle: anatomical variations, population frequencies and clinical implications

Pedro Angullo-Gómez et al., Quadriceps femoris systematic review

Pedro Angullo-Gómez[1], Cristina Jiménez-Luna[1, 2], Gloria Perazzoli[1, 2], Jose Prados[2, 3], Raul Ortiz[1, 2], Laura Cabeza[2, 3]

[1]Department of Anatomy and Embryology, University of Granada, Granada, Spain

[2]Institute of Biopathology and Regenerative Medicine (IBIMER), Center of Biomedical Research (CIBM), Granada University, Granada, Spain

[3]Instituto Biosanitario de Granada, (ibs. GRANADA), Granada, Spain

Address for correspondence: Dr. J. Prados, Institute of Biopathology and Regenerative Medicine (IBIMER), Department of Anatomy and Embryology, School of Medicine, University of Granada, 18100 Granada, Spain, tel: +34-958 248819, e-mail: jcprados@ugr.es

ABSTRACT

Recently, the classical anatomy of the quadriceps femoris has been questioned after the publication of various morphological variations that differ from the classical description. Therefore, it is necessary to collect information to reach an agreement on its structure. For this, a systematic review was carried out using the Web of Science, Pubmed and ProQuest scientific databases, obtaining a total of 29 papers finally included in the systematic review after being subjected to inclusion and exclusion criteria. The results obtained showed an important and variable prevalence of new configurations described, such as additional heads in the rectus femoris, a different origin of the vastus intermedius, various portions of the vastus lateralis, or the involvement of the vastus medialis in the patellofemoral musculature. For this reason, understanding the anatomy of the quadriceps femoris is a matter that has not yet been fully resolved, with high variability among people that must be studied prior to the application of an invasive and/or surgical procedure.

Keywords: anatomy, quadriceps femoris muscle, anatomical variation, population biological variation

INTRODUCTION

The anterior femoral compartment contains the hip flexor and knee extensor muscles: the iliopsoas, pectineus, sartorius, and quadriceps femoris muscles. The latter is a biarticular muscle innervated by the femoral nerve and irrigated by the femoral artery. It is a flexor of the hip, stabilizer of the patella, and extensor of the knee [1, 2].

Classical anatomical literature is quite consistent in describing the morphology of the quadriceps femoris muscle describing its composition by four muscle heads of origin, with a common final insertion through the quadriceps femoris tendon in the patella and its extension from the lower apex of the patella, the patellar ligament, finally inserting into the anterior tibial tuberosity [1, 2]. The rectus femoris muscle has a biarticular head with origin from the anterior inferior iliac spine and the supraacetabular groove. The vastus lateralis originates from the intertrochanteric line, the greater trochanter, the lateral lip of the linea aspera, and the lateral intermuscular septum. The vastus medialis arises from the intertrochanteric line, spiral line, and medial lip from the linea aspera. The origin of the vastus intermedius is the upper 2/3 of the anterior and lateral surface of the femoral body [3].

The quadriceps muscle plays a crucial role in standing, walking, running, and jumping (human motor skills), but its clinical role is equally important [4], being one of the most frequently injured muscles in sports (contusions, contractures and sprains).Patellofemoral pain syndrome is one of the most frequent musculoskeletal illnesses, mainly affecting the young population. Likewise, patellofemoral instability and rupture of the quadriceps tendon/patellar ligament are frequent in athletes and the active population [5]. Furthermore, it is relevant in reconstructive surgeries of the anterior and posterior cruciate ligament, external lateral ligament, and medial patellofemoral ligament [6]. All these lesions are painful and disabling, with frequent functional impotence, atrophy, sequelae, and morbidity of varying intensity [7].

Sometimes some subjects show an anatomical morphology different from that classically described, without pathological significance, known as anatomical variation, a common phenomenon in the population but largely unexplored [8]. Exhaustive and personalized knowledge of the anatomy of the structures involved in these cases is crucial for a correct diagnosis, planning, and treatment. Frequently, the anatomy found in clinical practice is more complex than that found in conventional anatomical literature [9]. In recent years, individual variations of the quadriceps femoris have been described, which could also be considered risk factors for some of the pathologies described above, which highlights the importance of knowing and describing these anatomical variations [10]. Therefore, it is necessary to perform a systematic search on the innovations in the last ten years in anatomical variations of the quadriceps femoris muscle, paying special attention to their population frequencies and clinical implications.

MATERIALS AND METHODS

Databases

In order to carry out this systematic review, the PRISMA guideline statement (Preferred Reporting Items for Systematic reviews and Meta-Analyses) were followed [11]. The bibliographic search was made in three electronic databases: Web of Science, Pubmed, and ProQuest. The search equation was constructed by the MeSH and DeCS terms as follows: “(Quadriceps femoris) AND (Anatomical Variations)”. The subject filter "muscles" was used in the ProQuest database. The search strategy was adapted for each of the databases used. In addition, the bibliography of the selected publications was reviewed, adding to the study the most relevant ones not included in the initial search result.

Inclusion and exclusion criteria

All studies from the last 10 years (between 2013 and 2023), all articles with full text available, conducted with humans from any population, related to macroscopic anatomical variations of the quadriceps femoris muscle and/or their clinical implications were included in the systematic review. Moreover, dissection studies, imaging studies, clinical cases, and systematic reviews of the literature available in English and Spanish were included. Likewise, research articles were included, excluding bibliographic reviews, conference proceedings, letters to the editor, and publications not subjected to peer review. All papers on topics unrelated to anatomical variations, anatomical variations of the lower limb not referring to the quadriceps femoris muscle, as well as those referring to non-human anatomy were excluded. No article was excluded based on geographical criteria.

Final selection of publications

The search equation previously described was used in the three platforms, and after applying the aforementioned inclusion and exclusion criteria, the following number of research papers were obtained: Web of Science 23, PubMed 38, and ProQuest 192 articles (Figure 1). After excluding the duplicates obtained (21 duplicate publications), 232 articles remained. The first screening was carried out based on the reading of its title and abstract. A total of 37 works were selected, which were submitted to the reading of the full text. In addition, by reviewing the bibliography of the obtained publications, 14 additional articles not previously obtained were added. Finally, 29 works were selected for the elaboration of this systematic review.

RESULTS

Among the 29 publications selected in this systematic review, 19 proposed the existence of new muscle heads, posing 35% of the publications alternative anatomical models

previously exposed in other articles, and 65% a new anatomical variation. In addition, the observed population frequency of these variations differs notably between the selected publications, finding from cases in isolated individuals to a presence of anatomical variations in 100% of the structures studied in the same work. Thus, there are publications in which the classical anatomy of the quadriceps femoris has been questioned, specifically 3 on the anatomy of the rectus femoris muscle, 1 on the vastus intermedius, 2 on the vastus lateralis, 4 on the vastus medialis and 19 on the number of muscle heads (anatomically interdependent between them). 10% of the works were published between 2013 and 2015, 38% between 2016 and 2019, and 52% between 2020 and 2023. Related to geographical distribution, 20 of these works were from Europe, while the rest were from America (4), Asia (4), and Oceania (1). The methodology used for the study of the anatomy of the quadriceps femoris was dissection (55%), imaging studies (21%), analysis of clinical cases (18%), or systematic reviews of the literature (6%) (Table 1).

Rectus femoris

It has been observed the existence of additional heads, such as an accessory head originating proximally together with the rectus femoris that runs independently through the anterior femoral compartment. In its distal region, it joins its aponeurosis together with that of the vastus lateralis muscle, forming part of the quadriceps femoris tendon (Figure 2) [6]. Also, the existence of 3 additional muscle heads has been observed: the most medial head originated from the proximal tendinous complex of the rectus femoris, the most lateral head originated from the deep surface of the fascia lata, and the intermediate head emerged jointly from the two regions described above, although in a more cranial location. Once originated, they converged, fusing their aponeuroses with that of the vastus lateralis and the rectus femoris, acquiring a chiasmatic morphology [9].

Likewise, a new connective tissue membrane has been found forming part of the proximal tendinous complex. It lies deep in the sartorius and iliopsoas muscles and originates from the anterior superior iliac spine, inserting distally on the proximal tendon of the rectus femoris. Regarding the longitudinal axis, the direct and indirect tendons of the rectus femoris run with an inclination medially, while the fibrous membrane does so laterally, so it may be involved in stabilizing muscle action in the transverse plane [35].

Vastus intermedius

The region of origin of the vastus intermedius is highly variable. The most common is found on the anterior and lateral surfaces of the femoral body (“contacting type”), reaching the lateral lip of the linea aspera, where it adjoins the vastus lateralis (69% frequency). The

least common originates from the anterior surface of the femoral body, without limiting to the vastus lateralis (“non-contacting type”) (31% frequency) (Figure 2) [3].

Vastus lateralis

A segmental anatomy of the vastus lateralis has been described with three muscular portions separated by two fibro-fatty planes that contain the vascular-nervous pedicle. Thus, the muscle is framed between a proximal-superficial aponeurosis and a distal-deep aponeurosis: (i) the superficial segment originated from the deep face of the proximal aponeurosis and the lateral intermuscular septum, being composed of a proximal tendinous half and a distal muscular half; (ii) the intermediate portion originated from the greater trochanter, ran the entire length of the vastus lateralis and had a fleshy conformation in its proximal region and fibrous in its distal region; (iii) the deep portion originated in the lateral intermuscular septum and the lateral labrum of the linea aspera and continued until it inserted into the quadriceps femoris tendon, so its fibers rotated anteriorly and may be responsible for stabilizing the patella, an antagonistic function to that of the vastus medialis muscle (Figure 2).

Likewise, an equally segmented neurovascular supply was observed. The superficial, intermediate, and deep portions of the vastus lateralis were supplied by the descending branch of the lateral femoral circumflex artery and the medial femoral nerve branch, the transverse branch of the lateral circumflex femoral artery and the lateral femoral nerve branch, and perforating branches of the deep femoral artery and the medial femoral nerve branch, respectively [13]. Within this segmental structure there is variability in the degree of interrelation of the different muscular portions. Thus, the connective tissue planes that limit the muscle segments were more evident in the ventral region, while they blurred dorsally, where the segments finally converged and interconnected [16].

Vastus medialis

Three studies included in this systematic review have described the vastus medialis obliquus (VMO) as independent within the vastus medialis without being able to conclusively demonstrate a correlation between selective structural affectation of the VMO and the symptoms of patients with patellar syndromes (Figure 2) [12, 14, 32]. Furthermore, the vastus medialis muscle did not seem the only muscle regulator of patellar lateral movement (specifically its distal region), suggesting the involvement of other components of the quadriceps femoris muscle [24].

In addition, Grob et al., [24] did not observe a clear myofascial separation dividing the vastus medialis nor an autonomous innervation for the segments of this muscle, finding, however, a more extensive muscle insertion than classically described. This insertion was

found not only in the quadriceps femoris tendon, the medial patellar margin, and the knee joint capsule, but it also is found inserted in the aponeurosis of the vastus intermedius muscle (100% of subjects studied). Therefore, the vastus medialis inserts mainly into the vastus medialis aponeurosis (longer insertion), thus dividing the vastus medialis insertion aponeurosis into a ventral and a dorsal portion when it reaches the medial border of the vastus intermedius, fusing again at its lateral border after having traversed its surface.

Extra muscle heads

The quadriceps femoris muscle is made up of 4 muscle bellies according to the traditional anatomical description; however, the existence of additional muscle bellies has been shown both by dissection and by imaging techniques (Figure 3) [15, 21, 25, 28]. Omakobia et al. [17] observed an additional muscle belly between the cranial region of the vastus intermedius and the vastus lateralis. This finding was of great surgical relevance since it made it impossible to obtain a muscle flap from the vastus lateralis. Another independent accessory muscle belly between the vastus intermedius and the lateralis was observed in a patient with a limitation of knee flexion to around 90º with separate insertion, origin, and course of both adjacent vastus [38]. Moreover, a fifth head of the quadriceps femoris has been frequently described, with origin between the intertrochanteric line and the greater trochanter of the femur, proximal to the vastus lateralis and located between the vastus intermedius and lateralis. This fifth muscular head was made up of a cranial belly, approximately 1/3 of its total length, which formed a long aponeurosis that ran through the entire femoral compartment, changing its position from lateral to distally anterior, to finally adopt a medial situation at the level of its tendon insertion, from which it was inserted into the medial portion of the patellar base [18]. The situation of this new muscle with respect to the rest of the muscles was very similar to that of the layers of an onion in the proximal region of the quadriceps femoris, finding consecutively from medial to lateral the bellies of the vastus intermedius, the new muscle, and the vastus lateralis, externally reinforced by the tensor fascia lata [21]. This new muscle head ran independently in its intermediate 1/3, while in its proximal and distal 1/3, the muscle belly and the caudal aponeurotic region showed great interindividual variability with the vastus intermedius and/or lateralis depending on its degree of development, distinguishing four variants, being the most common the independent variant (Table 2) [18, 22]. This new fifth head of the quadriceps femoris has enormous variability in its origin [33] and in its structure, with bilaminar morphology on some occasions [37], as well as penniform on others [34] (Table 3).

However, other works describe a constant muscular configuration in terms of the tendinous portion of the fifth muscle head in the region of the quadriceps femoris tendon with

three differentiated layers towards the depth of the muscle and two halves, one lateral and the other medial, highlighting the presence of the tendon of the fifth femoral head as an independent component and distinguishable as an autonomous entity [19]. At this point, it is important to highlight that for correct differentiation of the component muscle bellies of the quadriceps femoris, the separation of the muscle units during dissection should be done only with the fingers so as not to produce a false division of the muscle bellies [26].

Regarding the neurovascular supply of the fifth muscle belly, it had its own independent vessels and nerves through arteries that originated from the ascending and/or transverse branches of the lateral femoral circumflex artery and nerves from the lateral section of the femoral nerve [22, 26, 18]. In contrast, Ogami-Takamura et al. [28] did not find an independent innervation in all the fifth heads analyzed. The nerves analyzed came from nerves destined for the vastus lateralis or medialis.

Despite the large amount of recent information available on the morphology of this additional fifth muscular head, to date, no studies have assessed its biomechanics *in vivo*. A possible function is postulated both (i) in knee extension based on its close relationship with the vastus intermedius, being able to enhance its function by acting as a tensor of its muscle belly and its own patellar insertion; (ii) and in mediolateral patellar stabilization according to its trajectory, being able to counteract the effect of the medializing elements of the patella [29, 31].

DISCUSSION

Variability in the anatomy of the quadriceps femoris has been widely reported. Regarding the rectus femoris muscle, the variability of the biarticular belly of the quadriceps femoris muscle was previously documented, finding sources dating from the XIX century [39] and has continued to be documented recently [6, 9, 40]. Knowledge of these anatomical varieties is also relevant for clinical practice since the use of the rectus femoris tendon is frequent in reconstructive surgeries, in which, using it as the only graft source, is accompanied by an increased risk of rupture of the remaining tendon tissue. For these cases, the use of additional tendon structures could be very useful [6]. Regarding the finding of a connective tissue membrane in the proximal tendon complex of the rectus femoris by Mecho et al. [35], the evaluation of this structure should be included in the radiological examination of the patient with a rectus femoris tear, due to its close relationship with the myotendinous junction, the most frequent site of injury to this muscle. Furthermore, there are variations in the patellar tendon morphology that could be related with the development of some tendinopathies. This non-uniformity was not related with age but it was related with sex, where men’s had great grade of non-uniformity in the patellar tendon compared to women probably due to its varied proximal attachment [41]. In the case of quadriceps femoris with extra heads, it is postulated

that the patellar ligament is wider when there are additional heads, which could transfer more force to the knee than when there are no additional heads, and could be related to less loss of muscle strength of the quadriceps femoris or even less probability to knee injury [36]. This could be due to the layered composition of quadriceps femoris tendon which is ussualy structured in 4 layers: (1) superficially the rectus femoris tendon, (2) superficial portion of vastus medialis and vastus lateralis, (3) the intermediate portion of vastus lateralis and (4) deeply the vastus intermedius [42]. However, more layers can be found in the quadriceps femoris tendon in the case of the presence of additional heads such as a fifth layer when there is 5, 6 and even 8 quadriceps femoris heads [43]. Also, the variations of patellar ligament insertion angle could be related with the variability between subjects in quadriceps extension function during walking after anterior cruciate ligament injury, the development of degenerative damages of the knee cartilage, and with fat-pad and tendon pathologies [44,45].

The bibliographic information of the variations referring to the vastus intermedius is not abundant and the description of its muscular origin in the different publications is not consistent. Thus, we can find descriptions where the origin was in the lateral intermuscular septum, the upper portion of the lateral surface of the femur, and the upper portion of the anterior surface of the femur [3]. This variability in the origin of the vastus intermedius is relevant for clinical practice, especially in rehabilitation, since a relationship was observed with the intramuscular tension that the muscle is capable of generating, this being the component of the quadriceps femoris that makes the greatest contribution to knee extension [46].

Despite the large amount of available bibliography about the vastus lateralis, there is no consensus regarding its structure. For many years there were publications that described a stratified structure of the vastus lateralis subdivided into superficial and deep portions [39, 47, 48, 49], designating these segments as *vastus lateralis longus* (superficial belly with a longitudinal orientation of its fibers, inserted in the patellar base) and *vastus lateralis obliquus* (deep belly with a more transverse orientation of its fibers, inserted in the lateral patellar margin) [50]. A much more complex configuration has even been described where four muscle divisions could be differentiated based on the orientation of their muscle fibers [51].

The clinical relevance of the anatomical variations of the vastus lateralis is important in reconstructive surgery as it is a frequent site for obtaining pedicled and free flaps. However, quadriceps function is affected when a large flap is removed or when an imprecise intramuscular dissection is performed [52]. Therefore, a rigorous knowledge of the muscle morphology of this region is essential to reduce these sequelae. Thus, a new procedure has been designed to obtain conservative free muscle flaps from the vastus lateralis muscle based on its segmental anatomy [13].

A segmental division in the morphology of the vastus medialis has also been proposed based on the angulation of its muscle fibers, obtaining the name *vastus medialis longus* (VML) with its fibers oriented longitudinally with respect to the axis of the femur (located proximally, originating from the intertrochanteric line and the medial lip of the linea aspera), and *vastus medialis obliquus* (VMO) with an angulation of about 40-45º (located distally, originating from the medial intermuscular septum and the adductor magnus tendon) [53]. This new description of the morphology of the vastus medialis has been widely observed in different publications [4]. However, Hubbard et al., [54] concluded that the variability in the angulation of the muscle fibers observed was due to the extensive origin of the vastus medialis, and therefore this muscle should not be considered composed of two independent muscle bellies. Nevertheless, the VMO was accepted as an independent muscular entity, and rehabilitation protocols are used to selectively strengthen the VMO in patients with pain and/or patellofemoral instability [55]. Thus, the VMO is a patellar stabilizer, pulling the patella medially during contraction of the quadriceps femoris [53], controlling patellar lateral displacement not only through its distal region inserted in the patella but also pulling the body of the vastus intermedius, mediating its action through its most cranial fibers. In addition, this close interrelationship between the two vastus would be crucial for adequate knee extension, since the vastus medialis would also act to tense the vastus intermedius, thus increasing its intramuscular pressure to achieve a more effective muscle contraction [24]. Therefore, in relation to patellofemoral syndromes, it would be interesting to study in depth and in a personalized way the anatomy and existing anatomical variations of the quadriceps femoris with special attention to the distal region of the vastus medialis.

The existence of more than four muscle bellies in the quadriceps femoris muscle has been described for a long time [39, 56, 57, 58, 59, 60, 61, 62, 63]. More recent publications have described the existence of an accessory muscular head of the quadriceps femoris which seems to be present in a high population frequency (82%) called the *tensor vastus intermedius* muscle [18], which could be considered as a common constitutive element of the quadriceps femoris instead of an anatomical variant. However, other studies questioned whether this muscle is present in the majority of the population [26], or even whether it should be considered an independent entity based on innervation as a determining element of muscle homologies [28]. Therefore, despite the data presented, there is a lack of unanimity and the need to do more research in this regard. Furthermore, it should be noted that many of the studies made have a high risk of bias [29]. The clinical implications related to the existence of additional heads in the quadriceps femoris are evident as previously discussed in the results section [17, 23, 30, 38] and certain lesions have been erroneously attributed to the vastus intermedius or lateralis instead of the tensor vastus intermedius when is present [20].

Finally, this variability observed in the description of the quadriceps femoris morphology could also be due to a lack of consensus in the criteria used by different researchers to define an independent muscular entity. Thus, aspects such as their own identifiable origin, course, and insertion, being involved in their particular epimysium, having a distinguishable muscle function, or being innervated autonomously in such a way that a contraction independent of that of the rest of the adjacent musculature is possible, should be taken into account [26, 54]. Therefore, the study of the anatomy of the quadriceps femoris continues today to be a relevant subject for medical practice, requiring more research in this regard, which should be developed under unanimous standards and criteria.

CONCLUSIONS

After documenting numerous anatomical descriptions different from the classically accepted with a variable prevalence that ranges from reports of specific cases found by chance to a 100% presence in the samples studied, we can conclude that the structure of the quadriceps femoris is very complex and variable, that its understanding is necessary to guarantee quality healthcare, and that research in this regard has not been concluded and is currently booming. In this way, the presence of muscle heads and additional tendon structures belonging to the rectus femoris muscle, the diversity of the vastus medialis insertion, thus differentiating two well-distinguished morphological models, the stratified structure of the vastus lateralis muscle, and the close anatomical and functional interrelationship of the vastus medialis with its vast neighbors in the development of knee extension and patellar stabilization, have been observed. In addition, the existence of a fifth muscular head has been described by various authors, being found in 82% of the total of the 232 dissected lower extremities and in 100% of those evaluated by imaging techniques. It is necessary to carry out more research on the anatomy of the quadriceps femoris, with special emphasis on its application in the diagnosis of trauma pathology, in the development of rehabilitation plans, and in the application of different imaging techniques prior to orthopedic and reconstructive interventions where the anterior femoral compartment is involved, all with previously agreed unanimous criteria.

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Table 1. General characteristics of the articles included in the systematic review.

Type of study	Methodology	Results	Reference
Imaging	* NMR in patients with primary patella luxation and recurrent patella luxation	No significant differences were found in any of the parameters evaluated (cross-sectional area, penation angle, and cranial-caudal length of the vastus medialis oblique muscle) (n=82)	[12]
Dissection sand clinical cases	Protocolized macroscopic dissection. Establishment of surgical methodology with muscle grafts	New description of segmental anatomy of the vastus lateralis muscle, divided into three distinct and separate sections (n=10). New method of obtaining muscle graft (n=23)	[13]
Imaging	Ultrasonographic identification of the muscle bellies of the quadriceps femoris in patients with patellofemoral pain syndrome	Nonselective atrophy (n=35)	[14]
Imaging	Ultrasonographic	The tensor muscle of the vastus intermedius	[15]

	identification of a fifth head of the quadriceps femoris	was identified in its proximal (muscle belly), middle (aponeurosis), and distal (tendon) third in 100% of individual (n=10)	
Dissection sand clinical cases	Expansion of the research by Toia et al. (2015)	Description of the interindividual variability in the muscular interconnections of the dorsal region of the different segments of the vastus lateralis muscle	[16]
Clinical case	Finding in surgery to obtain muscle flap	Description of a “vestigial” muscle belly between the vastus lateralis and vastus intermedius that prevents to obtain a flap	[17]
Disecction	Protocolized macroscopic dissection	Description of a new muscular head independent of the quadriceps femoris, with a prevalence of 100% (n=26), with its own trajectory and innervation named "tensor vastus intermedius muscle"	[18]
Dissection	Protocolized macroscopic dissection	Description of the structure of the quadriceps femoris tendon with a multilayered conformation different from that classically described.Study of the contribution of the tensor muscle of the vastus intermedius to the tendon of the quadriceps femoris muscle	[19]
Clinical case and imaging	NMR	Patient with pain in the femoral region and knee after a fall. It is attributed to a rupture of the tensor muscle of the vastus intermedius	[20]
Dissection and imaging	Protocolized macroscopic dissection and NMR	Description of the interrelationships of the vastus lateralis, vastus intermedius, and tensor vastus intermedius muscles in the dorsal femoral region, as well as the appearance of the tensor vastus intermedius muscle	[21]
Dissection	Protocolized macroscopic dissection	Presence of the tensor vastus intermedius in 100% of the individuals analyzed (n=36), with an independent course, vascularization, and innervation	[22]
Clinical case and imaging	NMR	3-year-old subject with severe limitation in knee flexion with anodyne examination. NMR revealed an abnormality in the region corresponding to the vastus intermedius tensor Anatomopathological examination with fibrotic appearance	[23]
Dissection	Protocolized macroscopic dissection	Classification of the vastus intermedius muscle into two categories based on the variability of its proximal origin (n=33)	[3]
Dissection	Protocolized macroscopic dissection	Description of the insertion of the vastus medialis muscle into the vastus intermedius	[24]

		muscle aponeurosis, as well as its functional synergy	
Imaging	Ultrasonographic identification of the tensor vastus intermedius	After analysis of 21 limbs, the area of the fifth head of the quadriceps femoris was identified in 100% of the subjects. In addition, the increase in the area with the decrease in the angle of knee flexion was verified	[25]
Dissection	Protocolized macroscopic dissection	In the 20 dissected extremities, 35% found "pentaceps" morphology and 20% "triceps" morphology. In the 7 limbs with 5 heads analyzed, the fifth head was identified as the tensor muscle of the vastus intermedius	[26]
Dissection	Finding in routine dissection	Finding of an anatomical variant of the quadriceps with 7 femoral heads. Fifth femoral head was identified as the tensor vastus intermedius. 6th and 7th head, independent, emerging from the intertrochanteric line and the proximal 1/3 of the femur body respectively, fusing their aponeuroses distally to originate a common tendon in the medial femoral region	[27]
Dissection and imaging	Protocolized macroscopic dissection, study of peripheral nerves under a magnifying glass and *CT	Finding of a new muscular belly in 100% of the members evaluated. Gross description of an independent neurovascular supply. The nerves come from the fibers that innervate the vastus lateralis, questioning the existence of the fifth muscle belly as an independent entity (n=42)	[28]
Systematic review	Systematic search of bibliography regarding the tensor muscle of the vastus intermedius	Structured synthesis of identified findings and assessment of risk of bias	[29]
Clinical cases and imaging	*MRI	3 pediatric patients of course and nature identical to that reported by Sarassa et al. (2017)	[30]
Systematic review	Systematic search of bibliography regarding the tensor muscle of the vastus intermedius	Compilation of the main contributions made in recent years about the existence of the fifth additional femoral head	[31]
Imaging	CT of the cross-sectional area of the vastus lateralis and vastus medialis muscles in patients with patellofemoral pain syndrome	Existence of significant atrophy in both vastus, with no decrease in the ratio of the cross-sectional area of the vastus medialis oblique/vastus lateralis (n=61)	[32]

Dissection	Protocolized macroscopic dissection	Description of the fifth muscle head in 65% of the limbs analyzed (n=106)	[33]
Dissection	Finding in routine dissection	Identification of the fifth femoral head as a tensor muscle of the vastus intermedius, with penniform morphology, composed of four muscular sections joined medially consecutively to a single tendon	[34]
Dissection	Finding in routine dissection	Additional muscle head of the rectus femoris muscle	[6]
Dissection	Protocolized macroscopic dissection and NMR	Additional membranous origin of the proximal tendinous complex of the rectus femoris muscle (n=42)	[35]
Dissection	Extension of the research from Olewnik et al. (2021)	Report of a greater diameter of the myotendinous junction as well as of the patellar tendon in the lower limbs with a fifth muscular head of the quadriceps	[36]
Dissection	Finding in routine dissection	Identification of the fifth femoral head as a tensor muscle of the vastus intermedius, with bilaminar morphology. Identification of a previously unreported sixth femoral head emerging from the vastus medialis	[37]
Dissection	Finding in routine dissection	Three additional muscle heads of the rectus femoris muscle	[9]

*NMR: nuclear magnetic resonance. CT: computed tomography. MRI: magnetic resonance imaging.

Table 2. Classification of the interrelated variants of the fifth femoral head with the rest of the vastus of the quadriceps femoris proposed by Veeramani and Gnanasekaran [22].

Variant	Muscular origin	Distal aponeurosis
Type I: Independent Type	Independent	Independent
Type II: VI Type	Interconnected with the vastus intermedius	Fused with the vastus intermedius aponeurosis
Type III: VL Type	Interconnected with the vastus lateralis	Fused with de vastus lateralis aponeurosis
Type IV: Common Type	Interconnected with the vastus medialis and lateralis	Independent

* VI: vastus intermedius. VL: vastus lateralis.

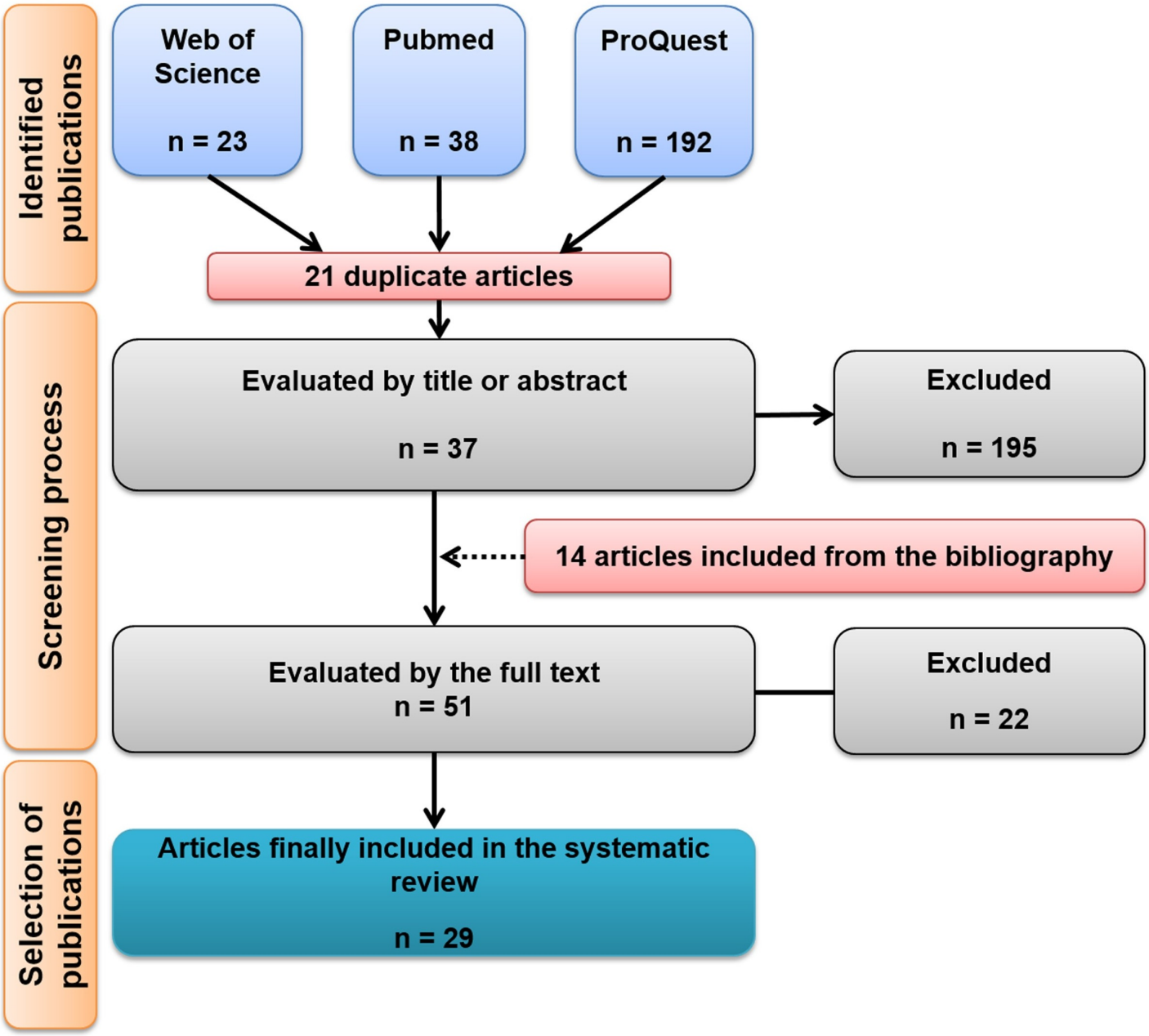
Table 3. Classification of the fifth head of the quadriceps femoris based on the variability of its muscular origin. The observed population frequencies are represented in parentheses.

Type	Characteristic	Subtype	Characteristic
I	A muscular belly with an independent origin (44.1%)	IA	Lateral location with respect to the vastus intermedius (29.4%)
		IB	Medial location with respect to the vastus intermedius (14.7%)
II	A muscular belly with an interrelated origin with other muscles (30.8%)	IIA	Connected to the vastus lateralis (23.5%)
		IIB	Connected to the vastus intermedius (4.5%)
		IIC	Connected to the gluteus minimus (2.9%)
III	Multiple muscle bellies (25%)	IIIA	Two muscle bellies (5.9%)
		IIIB	Two muscle bellies with independent aponeuroses (14.7%)
		IIIC	Three muscle bellies (2.9%)
		IIID	Four muscle bellies (1.5%)

Figure 1. Flow diagram of the selection process of the publications included in this systematic review.

Figure 2. Anatomic variations of quadriceps femoris. One or three additional heads of the rectus femoris and a connective tissue membrane from the superior iliac spite to the proximal tendon of the rectus femoris (A). Contacting and non-contacting type of the vastus intermedius. In the contacting type, VI is attached to lateral and anterior surfaces of femoral shaft and share the lateral lip of the line aspera with the origin of the VL. In the non-contacting type, VI is attached to the anterior surface of femoral shaft with no contact with line aspera (B). The segmental anatomy of the vastus lateralis with three muscular portions. They are distinguished a superficial segment (1), an intermediate portion (2), and a deep portion (3) of the muscle (C). Representation of an extended insertion of vastus medialis in the aponeurosis of the VI (D). Abbreviations: RF (rectus femoris), VL (vastus lateralis), VM (vastus medialis), VI (vastus intermedius), TFL (tensor fasciae latae), ANT (anterior), POST (posterior).

Figure 3. Extra heads of quadriceps femoris. Fifth head of the quadriceps femoris or the tensor vastus intermedius muscle (A) and the interrelated variants with the rest of the vastus of the quadriceps femoris (B). Extra bellies of tensor vastus intermedius muscle (C). Abbreviations: TVI (tensor vastus intermedius), VI (vastus intermedius), VM (vastus medialis), VL (vastus lateralis).


Identified publications
Screening process
Selection of publications
Web of Science
n = 23
Pubmed
n = 38
ProQuest
n = 192
21 duplicate articles
Evaluated by title or abstract
n = 37
Excluded
n = 195
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Evaluated by the full text
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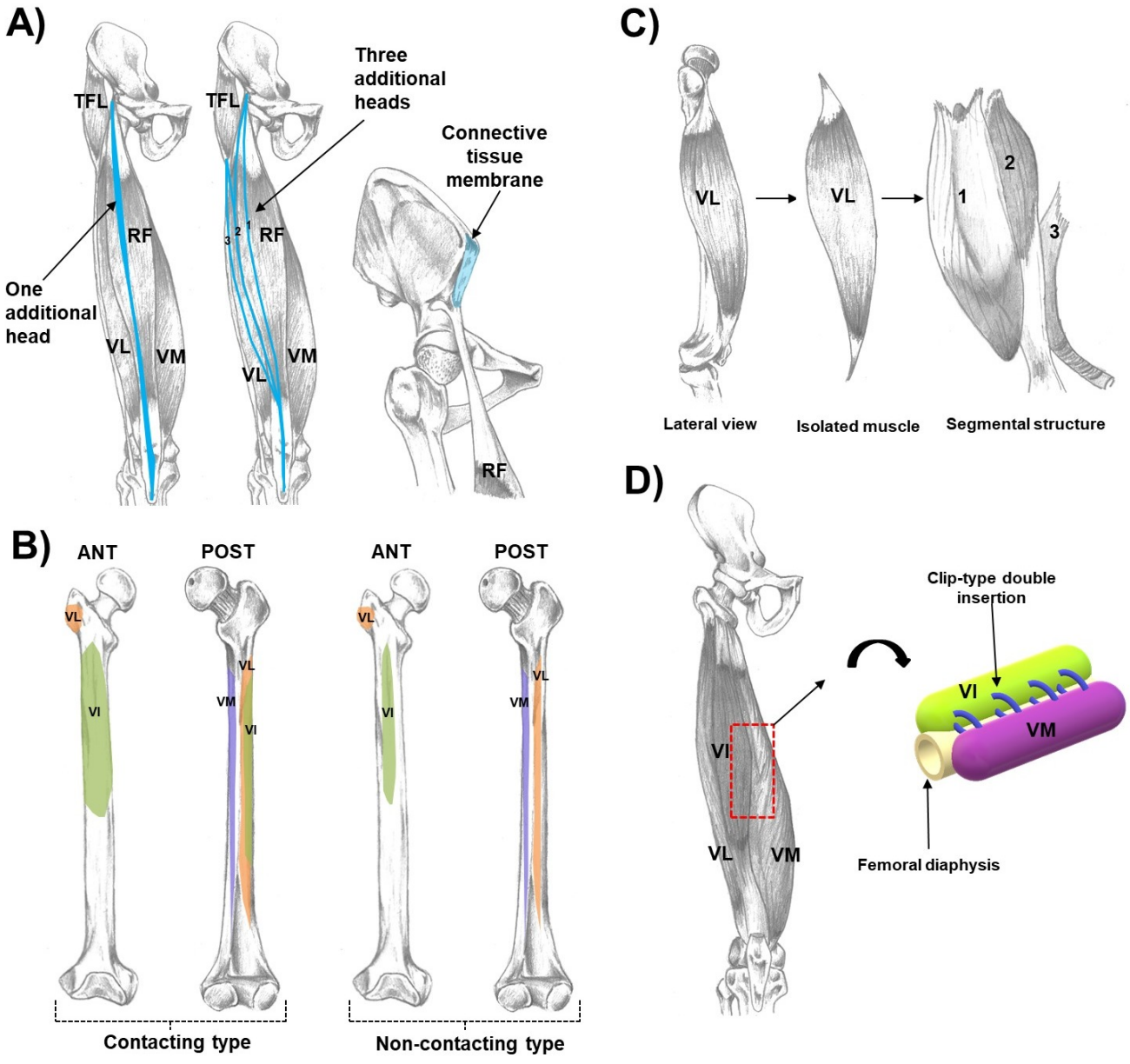
Excluded
n = 22
Articles finally included in the systematic review
n = 29


A)
TFL
RF
One additional head
VL
VM
TFL
Three additional heads
Connective tissue membrane
RF
VL
VM
RF
B)
ANT
POST
ANT
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VI
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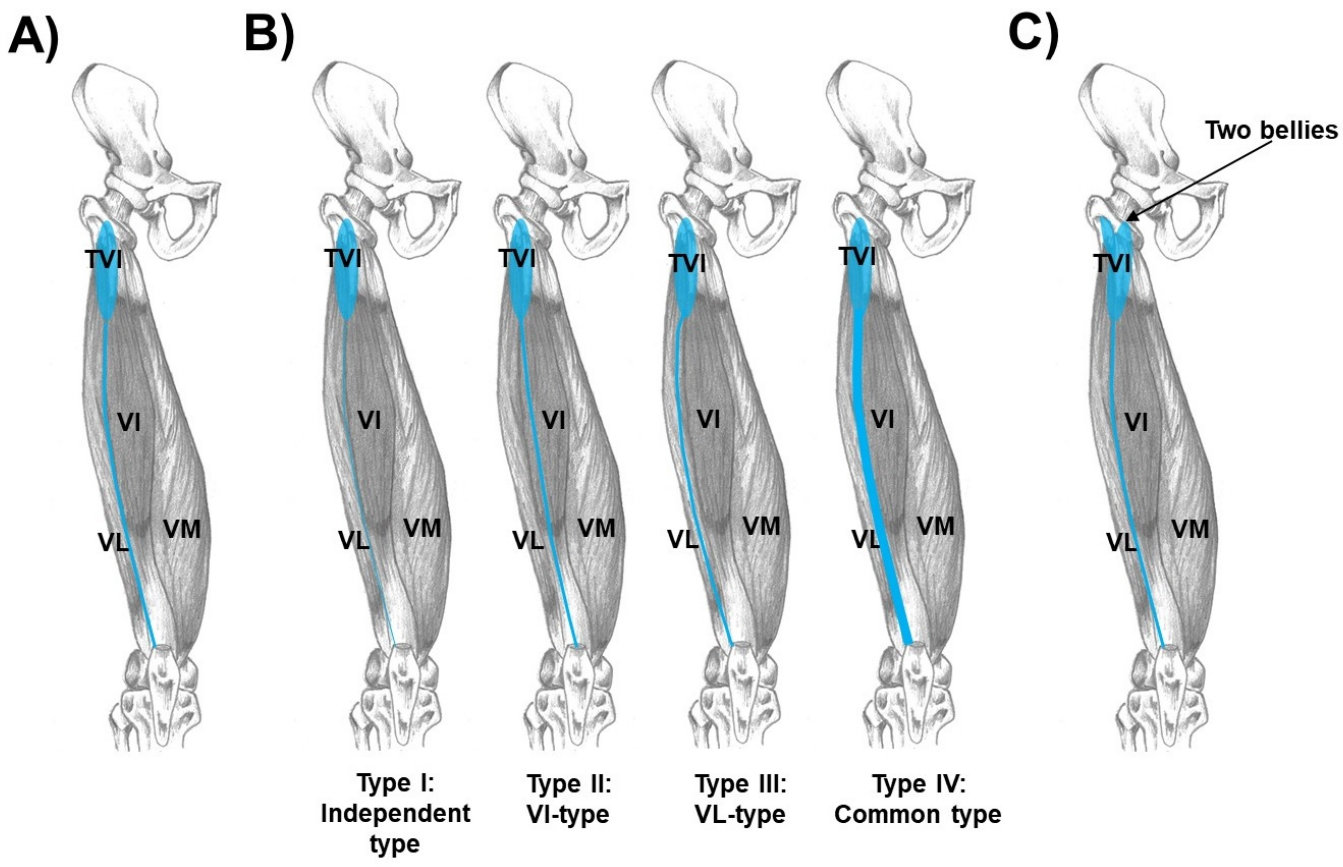
VI
VL
VI
VL
VM
Contacting type
Non-contacting type
C)
VL
VL
1
2
3
Lateral view
Isolated muscle
Segmental structure
D)
VI
VL
VM
Clip-type double insertion
VI
VM
Femoral diaphysis


A)
B)
C)
TVI
VI
VL
VM
Two bellies
Type I: Independent type
Type II: VI-type
Type III: VL-type
Type IV: Common type