Original Communication

Structural diversity of the vastus intermedius revealed by analysis of isolated muscle specimens

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Abbreviated title: Structure of vastus intermedius

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Abstract

Introduction: The (QF), a major extensor of the knee joint, plays an important role in human movement. However, descriptions of the three vastus muscles of QF remain confusing among anatomy textbooks. **Materials and Methods**: In the present study, we analyzed 33 QF with a newly invented methods employing isolated muscle specimens in order to clarify the origin structures of the vastus lateralis (VL), vastus medialis (VM), and vastus intermedius (VI). **Results**: The origins of the VL and VM were quite constant in shape and localization, whereas the VI exhibited structural diversity. In typical cases (23 of 33), the origin of the VI muscularly attached to the anterior and lateral surface of the femoral shaft. The origin of the VI adjoined that of the 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 the VI were much smaller than those in the typical cases. The origin of the VI attached only to the anterior surface of the femur and did not contact the lateral lip. In addition, the muscle belly of the VI was narrow and almost corresponded to the width of the femoral shaft. **Conclusion**: The isolated muscle specimen is a useful tool to analyze individual muscle structure, which can be difficult to observe by routine dissection. By using this method, it became clear that the VI exhibits wide structural diversity in its origin compared with the VL and VM.

Key Words: quadriceps femoris; vastus intermedius; muscle origin; anatomic variation

Introduction

The quadriceps femoris (QF), a major extensor of the knee joint, plays a crucial role in human movement, such as standing, walking, and running (Bleck, 1979; Montgomery et al., 1994; Blazevich et al., 2006). The QF consists of four separate parts, the rectus femoris (RF), vastus medialis (VM), vastus lateralis (VL), and vastus intermedius (VI) (Willan et al., 2002) (**Fig. 1A**). The RF only originates from the small area of bony pelvis (the inferior anterior iliac spine). On the other hand, the VM, VL and VI arise from the femur, but not the pelvis. The VM mainly arises from the medial lip of the liena aspera. The VL arises from the lateral lip of the liena aspera and the anterior aspect of the lateral intermuscular septum (LIS) (**Fig. 1A**). The medial edge of LIS is attached to the lateral lip, therefore the two attachment regions of VL are continuous.

The descriptions on the origin of the RF, VL, and VM is consistent in the anatomy textbooks as described above. However, the description of the origin of the VI is different among the anatomy textbooks (as summarized in Table 1). Some textbooks described the VI originates from both from the shaft of femur and the LIS (Poirier, 1893; Testut, 1899; Braus and Elze, 1954; Romanes, 1972; Moore, 1980; Hollinshead, 1982; Williams, 1995), but others did not include the LIS as the attachment site of VI (Henle, 1855; Gegenbaur, 1890; Davis-Colley and Bardeen, 1907; Frohse and Fränkel, 1913; Staubesand, 1985).

Recent anatomical studies on the QF frequently have distinguished the longitudinal and oblique parts of the VL (Becker et al., 2009). However, because these two parts and their mutual relationship have not been clearly defined (Vieira, 2011), the muscle belly found in the inferolateral part of the thigh has been regarded as either the oblique part of the VL (Hallisey et al., 1987; Bevilaqua-Grossi et al., 2004) or the lateral part of the VI (Tomita et al., 2015).

In the present study, in order to clarify the origin structures of the three vastus muscles of the QF, in particular the VI, we analyzed isolated QF specimens. The isolated muscle specimen is a useful tool to individual muscle structure, which can be difficult to observe by routine dissection.

Materials and Methods

Cadaveric source

All cadavers were from persons who donated their bodies for medical education and research to XXXXXX University School of Medicine. Prior to donation, written consent from persons and families was obtained. The protocol for the present research project was approved by the Ethics Committee of XXXXXX University School of Medicine (approval No. XXXXXX).

Thirty-three right lower extremities were collected from embalmed Japanese cadavers (21 males, 12 females; average age, 79.2 ± 10.9 years), which were dissected by medical students in the gross anatomy course at XXXXXX University School of Medicine. In our dissection protocol for medical students, the left legs were dissected to observe the bones and ligaments, therefore the muscles, nerves, and vasculature were severely destroyed in the left legs. We thus used only the right legs, where the muscles remained without severe structural damage, in the present study.

We excluded the cadavers which exhibited the significant pathologic alteration in muscles (such as muscular dystrophy, fatty degeneration, and large intramuscular hematoma), the traumatic lesions, and the operative scars.

Isolation of muscle specimens

The femoral muscles with fascia lata were exposed according to the routine procedures, and QF in the anterior fascial compartment was dissected out by removing the sartorius, hamstrings and adductor muscles. The isolated muscle specimens were prepared by detaching QF from the skeleton according to the following procedures (**Fig. 1B-D**). Firstly, the proximal end of RF was detached from the pelvis, and the distal tendon of QF together with the articular capsule of knee joint was cut around the superior and lateral margins of patella and horizontally on the both sides of patella at the level of articular space. The distal end of QF was then lifted upwards and the proximal attachment of QF together with intermuscular septa on the femur was recorded, and then detached from the femur. The articularis genus on the deep surface was removed, and the deep surface of specimens was cleaned by removing soft connective tissue and fat.

The isolated QF specimens preserved the fundamental structure of QF *in situ*. The advantage of isolated specimens over the *in situ* specimens was found on its deep surface. The deep surface of specimens was divided into origin and non-origin domains depending on the surface texture. The origin domain was covered with either dense connective tissue of periosteum or stout fascial intermuscular septum, whereas the non-origin domain was covered by loose connective tissue and easily denuded to expose muscular fibers by blunt dissection.

The direction of muscle fibers of vastus muscles was clearly determined in the isolated muscle specimens. According to the direction of muscle fibers, we could identify the boundaries among the origin domains of vastus muscles.

Results

The three vastus muscles in situ

First, we removed the QF together with the femur and intermuscular septum and observed the superficial structure of the QF *in situ* (**Fig. 1B**). The QF was a massive muscle almost completely wrapping the femoral shaft (**Fig. 1B'**), except for the region between the lateral and medial lips of the linea aspera (**Fig. 1B", C"**).

When viewed from the anterior side, the RF, VL, and VM were easily recognized (**Fig. 1B'**). As indicated by previous studies, the VL consisted of the main longitudinal part (VL-L) and the inferolateral oblique part (VL-O) (Hallisey et al., 1987; Bevilaqua-Grossi et al., 2004; Becker et al., 2009) (**Fig. 1D', D"**). The VI was almost completely covered by the RF and VL-L, but could be partially seen when the RF was removed (**Fig. 1B', D'**).

When viewed from the posterior side, the LIS was clearly recognized as a thick fibrous membrane (**Fig. 1B"**). The medial end of the LIS was attached to the lateral lip (**Fig. 1C"**), while the lateral end continued the iliotibial tract (data not shown). Unlike the LIS, the medial intermuscular septum was recognized as loose connective tissue that was easily removed by blunt dissection with tweezers. Instead of the medial intermuscular septum, the membranous tendon of origin of the VM attached to the medial lip (**Fig. 1B", C"**).

Origins of the three vastus muscles

We could easily confirm that the RF originated from the inferior anterior iliac spine without observing the isolated muscle specimens, but to precisely examine the origin structures of the VL, VM, and VI, we needed to isolate the QF together with the LIS from the femur (**Fig. 2**). The deep surface of the QF, which faced the femur and LIS, was subdivided into origin and non-origin domains. The origin domain arose directly from either the femur or the LIS, and was not easy to separate from these structures due to dense connection. On the other hand, the non-origin domain had indirect contact with the femur via loose connective tissue containing adipose tissue, and was easily detached from the femur. In all of the isolated specimens, we found the articularis genus on their deep surface and removed it from the vastus intermedius.

Origins of VL and VM

The VL possessed a stout membranous origin tendon on the superficial surface arising from the superior portion of femur including the greater trochanter (**Figs. 1C', 2A1–2**). On the deep surface of specimens, the origin domain of VL was found in the lateral region and divided into two subdomains, one for VL-L arising from both the femur and superior part of LIS, and the other for VL-O arising from the inferior part of LIS (**Fig. 2C1–3**). The origin domain of VL-L was further demarcated at its attachment to the lateral lip of the linea aspera into a superomedial part arising from the femur and an inferolateral part arising from LIS (arrowheads in **Fig. 2C1–3**). The superomedial part of VL-L origin domain arose from the superior portion of femur containing the anterior aspect of the greater trochanter, the small area of the gluteal tuberosity, and the superior one-fourth of the lateral lip (dark green area in **Fig. 2C2–3**). On the other hand, the inferolateral part of VL-L domain arose muscularly from the superior one-fourth of the anterior aspect of the LIS without tendon formation (light green area in **Fig. 2C2–3**). The origin domain of VL-O attached muscularly to the inferior three-fourths of the anterior aspect of the LIS also without tendon formation (blue area in **Fig. 2C2–3**). In all of the specimens examined, the origin domains of the VL-L and VL-O were continuous to form a single domain which was almost constant in shape and location.

The VM possessed a narrow membranous origin tendon on the superficial surface arising from the posterior aspect of femur (solid circles in **Fig. 2A1–2**). On the deep surface of specimens, the origin domain of VM was found along the medial edge arising solely from the posterior region of femur containing the intertrochanteric line and the medial lip of linea aspera (purple area in **Figs. 1C2", 2C2–3**), and not from the intermuscular septum, since the medial part of intermuscular space was formed by loose connective tissue containing blood vessels and nerves practically lacking fascial intermuscular septum. In all of the specimens examined, the origin domain of the VM exhibited almost constant in shape and location (**Fig. 3**).

Origin of VI

The VI typically arose muscularly from the anterior and lateral aspect of femur without origin tendon (**Figs. 1C', 2B1–2**). On the deep surface of specimens, the origin domain of VI was found in the superior two thirds of central region arising from the femur (**Fig. 2C1–2**). The shape and area of the origin domain of VI exhibited remarkable diversity compared with those of VL and VM (**Fig. 3**). In particular, the topographical variation of origin domain of the VI was remarkable in relation to the origin domain of VL, either contacting the lateral lip of linea aspera forming a continuous region with that of VL (**Figs. 3A1–23, 4A1–2**) or separated from it forming an isolated region (**Figs. 3B1–10, 4B1–2**). Thus, we classified the origin domain of the VI into contacting and non-contacting types based on its positional relationship to the origin domain of the VL.

In the contacting type (23 of 33 cases), the origin domain of the VI muscularly attached to the anterior and lateral surface of the femoral shaft (**Fig. 4A1–2**). The muscle belly of the VI decreased in thickness from its anterior to lateral parts. The origin domain of the VI adjoined that of the VL-L at the lateral lip of the linea aspera to form a common origin domain.

In the non-contacting type (10 of 33 cases), the muscle belly and origin domain of the VI were much smaller than those in the contacting type (**Fig. 3**). The origin domain of the VI attached only to the anterior surface of the femur and did not contact the lateral lip of the linea aspera (**Fig. 4B1–2**). The muscle belly of the VI was narrow and almost corresponded to the width of the femoral shaft. The non-origin domain of the VL was seen between the origin domains of the VI and VL.

Discussion

Anatomical analysis of the three vastus muscles can be difficult due to their broad attachment to the femur, which makes them hardly manipulable in embalmed cadavers. In the present study, we analyzed isolated QF specimens, which allow for manipulation without restriction by the skeleton and direct observation of the deep surface of the muscles. By using this method, we precisely determined the origins of the three vastus muscles and found wide structural diversity of the VI.

The three-dimensional relation between muscles and skeletons is crucial to understand the muscle function, but this relation is completely disrupted in the isolated muscle specimens. The *in situ* muscle specimens that remain the attachment to the skeletons have an advantage in the anatomical analysis of muscle function. Therefore, to comprehensively understand the structure and function of muscles, it was needed to analyze both *in situ* and isolated muscle specimens.

In previous anatomy textbooks, the origin of the VI from the femur was consistently regarded as the anterior and lateral aspects of the femoral shaft (Table 1). However, the description of the origin of the VI from the LIS was controversial. Some textbooks described the VI as originating from the anterior aspect of the LIS with or without the VL (Poirier, 1893; Testut, 1899; Braus and Elze, 1954; Romanes, 1972; Moore, 1980; Hollinshead, 1982; Williams, 1995). Others did not mention the origin of the VI from the LIS (Henle, 1855; Gegenbaur, 1890; Davis-Colley and Bardeen, 1907; Frohse and Fränkel, 1913; Staubesand, 1985). Based on the present study using isolated muscle specimens, we confirmed that the VI originated only from the femoral shaft, and not from the LIS, as described by the latter group of textbooks.

In this study, we also revealed that the origin domains of the VL and VM were relatively constant in shape and localization, but that the VI exhibited structural diversity, which has not been reported to the best of our knowledge. There are some reasons why the structural diversity of the VI has not been recognized. One is a methodologic reason. Previous anatomical studies were based on observation of skeletal muscles attached to the skeleton *in situ*. Although this ordinal method has the advantage of easy comprehension of muscle action on the skeleton, it is difficult to observe the deep attachment of the VI. Another reason is that the origin of the VI is not frequently treated during major surgical procedures on the hip joint.

The muscle fusion between the VL and VI has been reported in previous studies (Willan et al., 1990; Becker et al., 2009). In an extreme case, described that the VL and VI could not be distinguished, and, instead, that the extensor apparatus of the knee could be regarded to possess only three muscle heads (Frohse and Fränkel, 1913). In the contacting type of VI, which was described here, the origin domains of the VL and VI were continuous. Thus, the QF associated with the contacting type of VI could be regarded as the "triceps femoris," as mentioned by (Frohse and Fränkel, 1913). However, the QF associated with the non-contacting type of VI clearly exhibited four separate muscle heads, as previously considered.

The structural diversity of the VI origin domain observed in the present study was simply correlated with the difference of muscle mass of VI. The muscle belly of the VI had constant location and morphology attaching to the anterior aspect of the femoral shaft, and decreasing thickness from the anterior to lateral parts. The contacting type of VI with larger origin domain would be explained by extensive development and lateral expansion of VI, while the non-contacting type with smaller origin domain would be resulted from poor development and limited mass of VI. We could not find any sings of difference of developmental origin of VI from the muscle morphology, although we could not analyze the innervation of VI due to limitation of methods using the isolated muscle specimens.

The functional contribution of VI was estimated to be largest among the three vastus muscles of QF (Zhang et al., 2003). Recent investigators tried to measure the electromyographic activity of VI by surface and needle electrodes, on the assumption that the inferolateral part of QF would represent VI on the basis of MRI imaging (Watanabe and Akima, 2009; Saito and Akima, 2015; Tomita et al., 2015), but the present study revealed undoubtedly that this muscular part actually represented VL-O instead of VI. Furthermore in view of the conspicuous variation in the expansion of origin domain as well as muscle mass of VI, the feasibility of simple estimation of major functional role of VI in knee flexion appeared to be doubtful. Concerning the clinical aspects, VI did not became a specific site of traumatic injuries or objects of surgical intervention, except for rare cases such as VI tendon rupture (Thompson et al., 2008; Cetinkaya et al., 2015) or trans-VI transfer of pedicled thigh flap (Batdorf et al., 2013), because of its deep location in the thigh covered by the other vastus muscles.

As a future issue, we need to evaluate the morphology of the VI and to examine how the structural diversity of the VI influences the movement of the knee joint and the stability of the patellofemoral joint. Now we first challenges to evaluate the three-dimensional morphology of the three vastus muscles in healthy living individuals by using magnetic resonance imaging and reconstruction technique.

In conclusion, the isolated muscle specimen is a useful tool to analyze individual muscle structure. By using this method, it became clear that the VI exhibits wide structural diversity in its origin compared with the VL and VM.

Acknowledgments

The authors wish to thank Dr. XXXXXX, Mr. XXXXXX, and Mr. XXXXXX for their skillful technical assistance. The authors also gratefully thank the individuals who donated their bodies to XXXXXX University School of Medicine. This article was made possible by the selfless gift from donor cadaver persons.

Conflicts of interest

The authors have no conflicts of interest to declare.

References

Batdorf NJ, Lettieri SC, Saint-Cyr M. 2013. Trans-vastus Intermedius Transfer of the Pedicled Anterolateral Thigh Flap for Posterior Thigh Reconstruction. Plastic and Reconstructive Surgery Global Open 1.

Becker I, Woodley SJ, Baxter GD. 2009. Gross morphology of the vastus lateralis muscle: An anatomical review. Clin Anat 22:436-450.

Bevilaqua-Grossi D, Monteiro-Pedro V, Sousa GC, Silva Z, Bérzin F. 2004. Contribution to the anatomical study of the oblique portion of the vastus lateralis muscle. Braz J Morphol Sci 21:47-52.

Blazevich AJ, Gill ND, Zhou S. 2006. Intra- and intermuscular variation in human quadriceps femoris architecture assessed in vivo. J Anat 209:289-310.

Bleck EE. 1979. Orthopaedic management of cerebral palsy. In: In: Sledge CB e, editor. Saunders monographs in clinical orthopaedics. London: W.B. Saunders Company.

Braus H, Elze C. 1954. Anatomie des Menschen. In, 3rd ed. Berlin: Springer. p 514-518.

Cetinkaya E, Aydin CG, Akman YE, Gul M, Arikan Y, Aycan OE, Kabukcuoglu YS. 2015. A rare knee extensor mechanism injury: Vastus intermedius tendon rupture. International journal of surgery case reports 14:186-188.

Davis-Colley JNC, Bardeen CR. 1907. The musculature. In: Morris's Human anatomy: a complete systematic treatise by English and American authors, 4th ed. Philadelphia: P. Blakiston's Son. p 315-477.

Frohse F, Fränkel M. 1913. Die Muskeln des Menschlichen Beine. In: Bardeleben K, editor. Handbuch der Anatomie des Mensche, 1st ed. Jena: Gustav Fischer. p 507-519.

Gegenbaur C. 1890. Lehrbuch der Anatomie des Menschen. In, 4th ed. Leipzig:

Wilhelm Engelmann. p 442-444.

Hallisey MJ, Doherty N, Bennett WF, Fulkerson JP. 1987. Anatomy of the junction of the vastus lateralis tendon and the patella. J Bone Joint Surg Am 69:545-549.

Henle J. 1855. Handbuch der Muskellehre des Menschen. In: Handbuch der systematischen Anatomie des Menschen, 1st ed. Braunschweig: Friedrich Vieweg und Sohn. p 258-264.

Hollinshead WH. 1982. Anatomy for Surgeons: the Back and Limbs. In, 3rd ed. Philadelphia: Harper & Row. p 692-696.

Montgomery WH, Pink M, Perry J. 1994. Electromyographic analysis of hip and knee musculature during running. The American journal of sports medicine 22:272-278.

Moore KL. 1980. Clinically Oriented Anatomy. In, 1st ed. Baltimore: Williams & Wilkins. p 441-447.

Poirier P. 1893. Muscles du membre abdominal. In: Richer P, editor. Traite d'Anatomie Humanine, 1st ed. Paris: L. Battaille ET Cie. p 213-224.

Romanes GJ. 1972. Cunningham's Textbook of Anatomy. In, 11th ed. London: Oxford University Press. p 372-374.

Saito A, Akima H. 2015. Neuromuscular activation of the vastus intermedius muscle during isometric hip flexion. PloS one 10:e0141146.

Staubesand J. 1985. Untere Gliedmaßen. In: Benninghoff Makroskopische und mikroskopische Anatomie des Menschen, 14th ed. München: Urban & Schwarzenberg. p 353-354.

Testut JL. 1899. Traité d'anatomie humaine. In, 4th ed. Paris: Octave Doin. p 935-937.

Thompson S, Bird J, Somashekar N, Dick E, Spicer D. 2008. Investigation and treatment for isolated vastus intermedius rupture. Injury Extra 39:232-234.

Tomita A, Ando R, Saito A, Watanabe K, Akima H. 2015. Effect of interelectrode distance on surface electromyographic signals of vastus intermedius muscle in women and men. J Electromyogr Kinesiol 25:841-846.

Vieira EPL. 2011. Anatomic study of the portions long and oblique of the vastus lateralis and vastus medialis muscles: review article. J Morphol Sci 28:228-234.

Watanabe K, Akima H. 2009. Cross-talk from adjacent muscle has a negligible effect on surface electromyographic activity of vastus intermedius muscle during isometric contraction. Journal of Electromyography and Kinesiology 19:e280-e289.

Willan PL, Ransome JA, Mahon M. 2002. Variability in human quadriceps muscles: quantitative study and review of clinical literature. Clin Anat 15:116-128.

Willan PLT, Mahon M, Golland JA. 1990. Morphological variations of the human vastus lateralis muscle. J Anat 168:235-239.

Williams PL. 1995. Muscles. In: in: Salmons S e, editor. Gray's Anatomy: anatomical basis of medicine and surgery, 38th ed. London: Churchill Livingstone. p 873.

Zhang LQ, Wang G, Nuber GW, Press JM, Koh JL. 2003. In vivo load sharing among the quadriceps components. Journal of orthopaedic research 21:565-571.

Figure Legends

Figure 1. Process of isolation of quadriceps femoris (QF) is explained by schematic drawings (**A**-**D**) and photographs (**B'**-**D'**, **B"**-**D"**). (**A**) Un-dissected right tight. Cross section at the middle of thigh. The five parts of QF are depicted in green (longitudinal part of the vastus lateralis [VL-L]), blue (oblique part of the vastus lateralis [VL-O]), yellow (vastus intermedius [VI]), purple (vastus medialis [VM]), and gray (rectus femoris [RF]). (**B**, **B'**, **B"**) Isolated QF together with the femur and lateral intermuscular septum (LIS) from the right thigh. The femur and QF are subsequently separated by sharp dissection as indicated by a long double arrow. The RF is reflected downward to expose the VI (**B'**). (**C**, **C'**, **C"**) Isolated femur. The attachment sites of the three vastus muscles on the femur are depicted in green (VL-L), blue (VL-O), yellow (VI), and purple (VM). The VL-O and VM are attached to the lateral lip (LL) and medial lip (ML) of the linea aspera. (**D**, **D'**, **D"**) QF isolated from the femur. The specimen is unfolded. The RF is reflected downward to expose the VI (**D'**). Asterisks in **D'**, origin tendon of VL-L; Solid circles in **D'**, origin tendon of VM; Arrowhead in **D"**, attachment site to the lateral lip. (**B'**, **C'**) Anterior view. (**B"**, **C"**) Posterior view. (**D'**) Superficial surface view. (**D"**) Deep surface view. Abbreviations: GT, greater trochanter.

Figure 2. Superficial and deep surfaces of isolated right QF. (**A1**, **A2**, **B1**, **B2**) Superficial surface view of the three vastus muscles. The RF is reflected downward to expose the VI. Membranous origin tendons are found at the VL-L (asterisks in **A1**, **A2**) and the VM (solid circles in **A1**, **A2**). In **B1** and **B2**, the VL-L is reflected to further expose the VI. Membranous insertion tendons are found on the VL-L (asterisks in **B1**,

B2) and the VI (solid circles in **B1**, **B2**). (**C1**, **C2**, **C3**) Deep surface view of the three vastus muscles. The origin domains are depicted in yellow (VI), blue (VL-O), and purple (VM). The VI exhibits a contacting type of origin domain. The origin domain of the VL-L is subdivided into the superomedial and inferolateral parts by its attachment to the lateral lip (LL) of the linea aspera (arrowheads in **C2**, **C3**). The superomedial and inferolateral parts are depicted in dark and light green, respectively. (**C3**) The three vastus muscles separated by sharp dissection.

Figure 3. Schematic illustrations showing the origin domains of the three vastus muscles in all of the cases examined. The origin domains of the longitudinal part of the vastus lateralis (VL, green), oblique part of the VL (blue), and vastus medialis (purple) were quite constant in shape and localization, whereas the vastus intermedius (VI, yellow) exhibited wide structural diversity. The origin domain of the VI was subdivided into contacting and non-contacting types based on the positional relationship to the origin domain of the VL. In the contacting type (23 of 33 cases, **A1–A23**), the origin domain of the VI muscularly attached to the anterior and lateral surface of the femoral shaft. The origin domain of the VI adjoined that of the VL at the lateral lip of the linea aspera to form a common origin domain. A deep indentation was frequently found at the origin domain of the VI (arrows in **A6**, **A9**, **A10**, **A13–A16**, **A18–A20**, and **A23**). In the non-contacting type (10 of 33 cases, **B1–B10**), the muscle belly and origin domain of the VI were much smaller than those in the contacting type. The origin domain of the VI attached only to the anterior surface of the femur and did not contact the lateral lip. In addition, the muscle belly of the VI was narrow and almost corresponded to the width of the femoral shaft. Abbreviations: I,

vastus intermedius; L, longitudinal part of the vastus lateralis; M, vastus medialis; O, oblique part of the vastus lateralis.

Figure 4. Schematic illustrations showing the attachment sites of the VI on the femur in the cases of contacting type (**A1**, **A2**) and non-contacting type (**B1**, **B2**). The attachment sites are depicted in yellow (VI), green (VL-L), blue (VL-O), and purple (VM). (**A1**, **B1**) Anterior view. (**A2**, **B2**) Posterior view. GT, greater trochanter; LL, lateral lip; ML, medial lip.

Table 1. Descriptions of the vastus muscles among anatomy textbooks

Book title	Author(s) (year)	Vastus muscles originating from LIS		Origin of VI from femoral shaft
Gray's Anatomy (38th ed.)	Williams (1995)	VL	VI	Anterior and lateral
Cunningham's Textbook of Anatomy (11th ed.)	Romanes (1972)	VL	VI	Anterior and lateral
Clinically Oriented Anatomy (1st ed.)	Moore (1980)	VL	VI	Anterior and lateral
Anatomy for Surgeons (3rd ed.)	Hollinshead (1982)	VL	VI	Anterior and lateral
Morris's Human Anatomy (4th ed.)	Davis-Colley and Bardeen (1907)	VL		Anterior and lateral
Handbuch der Muskellehre des Menschen (1st ed.)	Henle (1855)	VL		Anterior
Lehrbuch der Anatomie des Menschen (4th ed.)	Gegenbaur (1890)	VL		Anterior and lateral
Anatomie des Menschen (3rd ed.)	Braus and Elze (1954)		VI	Anterior and lateral
Benninghoff's Makroskopische und Mikroskopische Anatomie des Menschen (14th ed.)	Staubesand (1985)			Anterior and lateral
Handbuch der Anatomie des Menschen (1st ed.)	Frohse and Fränkel (1913)	VL		Anterior
Traité d'Anatomie Humaine (4th ed.)	Testut (1899)		VI	Anterior and lateral
Traite d'Anatomie Humaine (1st ed.)	Poirier (1893)	VL	VI	Anterior and lateral

Abbreviations: LIS, lateral intermuscular septum; VI, vastus intermedius; VL, vastus lateralis.

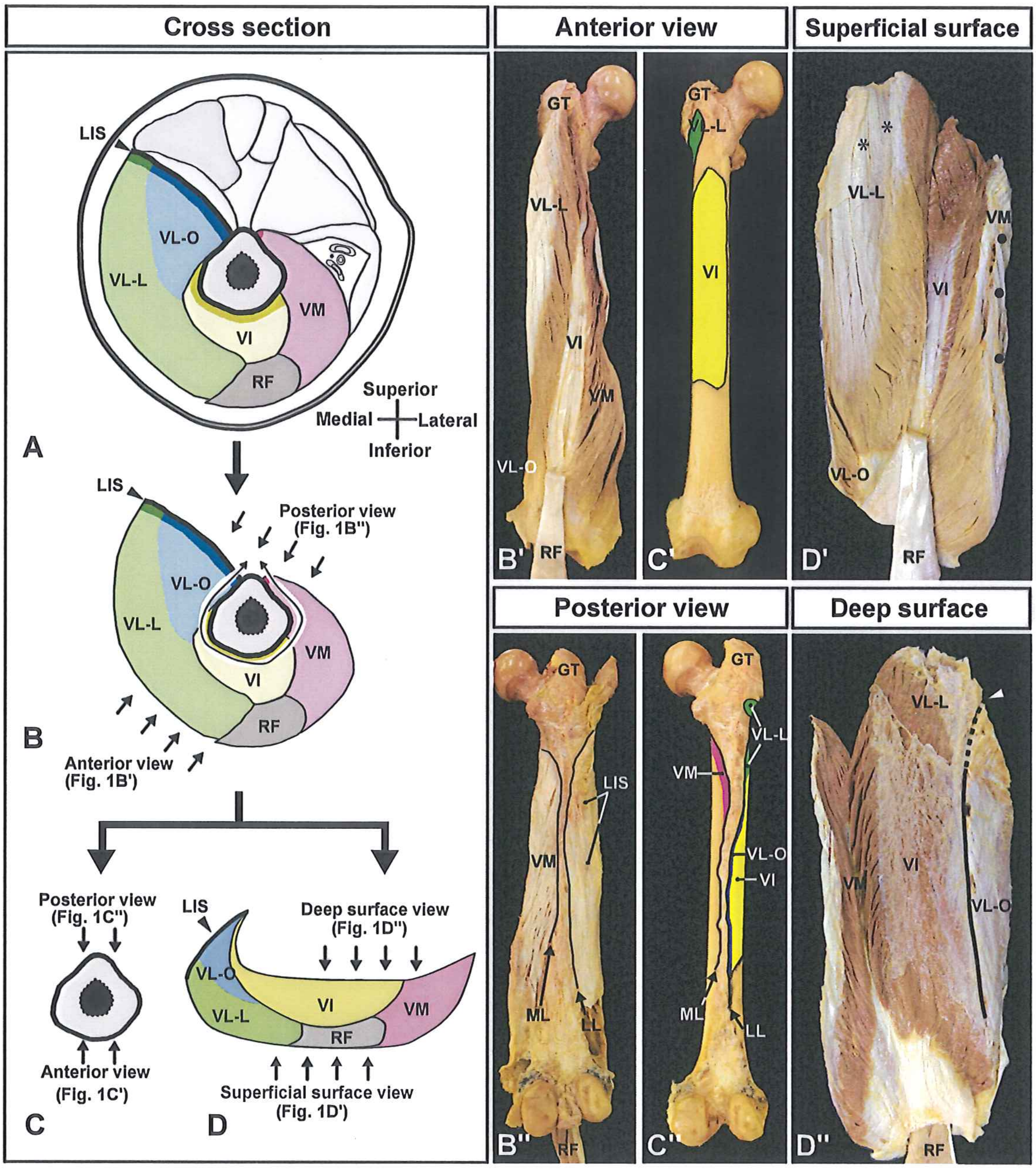

Figure 1
Yoshida et al.

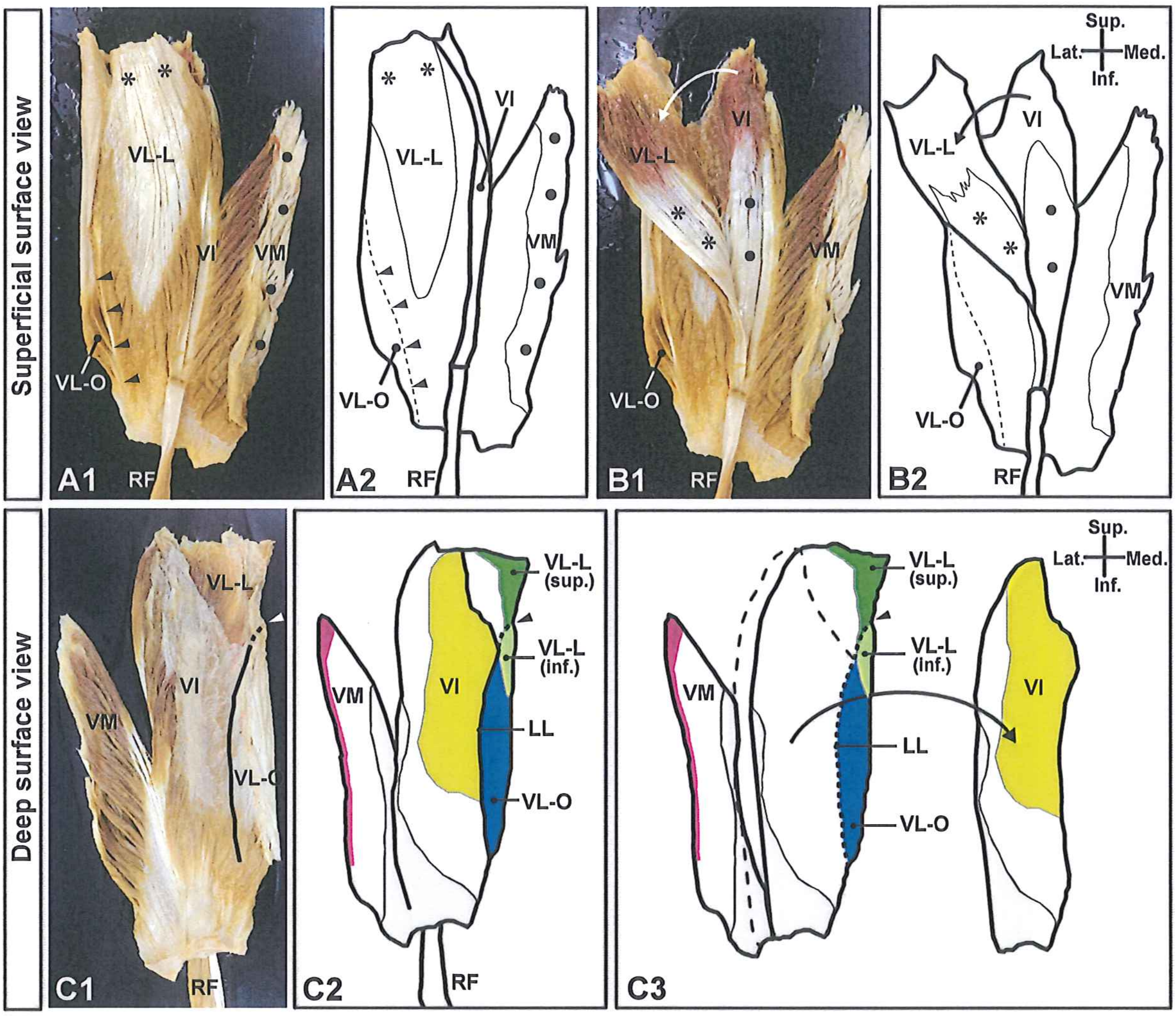

Figure 2
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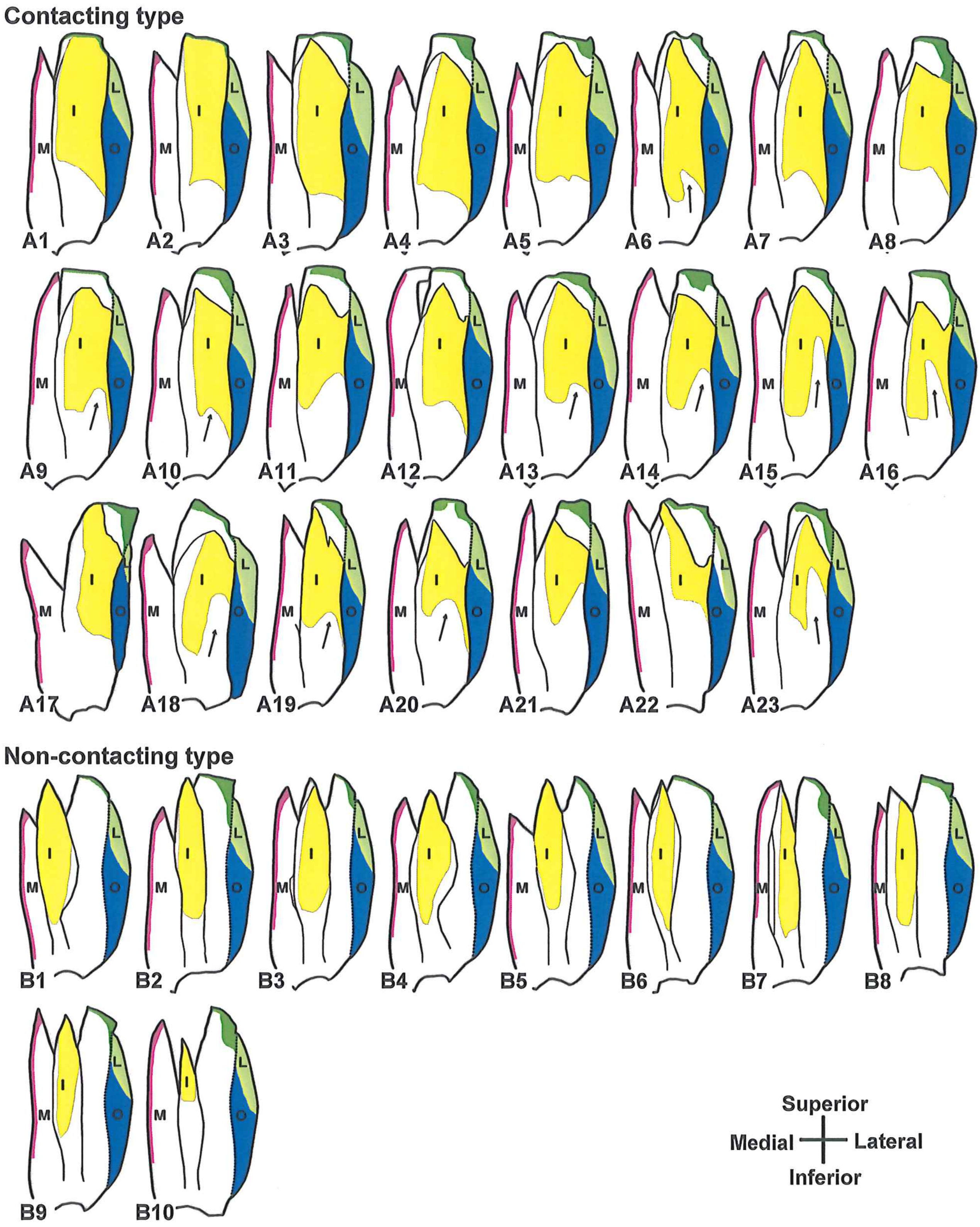

Figure 3
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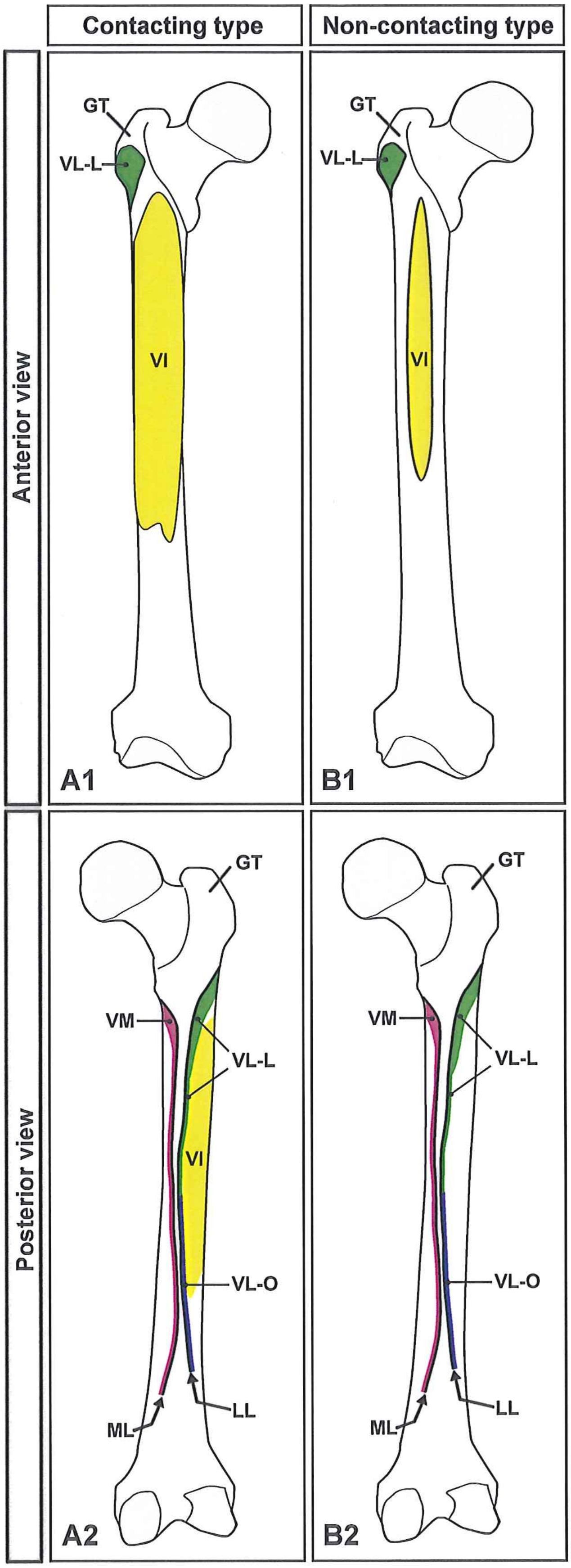

Figure 4
Yoshida et al.