Structural Diversity of the Vastus Intermedius Origin Revealed by Analysis of Isolated Muscle Specimens

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The quadriceps femoris (QF), a major extensor of the knee joint, plays an important role in human movement. However, descriptions of the three vastus muscles of the QF in anatomy textbooks remain confusing. We analyzed 33 QFs by a novel approach, using isolated muscle specimens to clarify the structures of the vastus lateralis (VL), vastus medialis (VM), and vastus intermedius (VI) origins. The origins of the VL and VM were quite constant in shape and location, but the VI was much more structurally diverse. In typical cases (23 of 33), the origin of the VI attached muscularly to the anterior and lateral surface of the femoral shaft. It adjoined the origin of the VL at the lateral lip (LL) 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 LL. In addition, the muscle belly of the VI was narrow and almost corresponded to the width of the femoral shaft. The isolated muscle specimen is a useful tool for analyzing individual muscle structures, which can be difficult to observe by routine dissection. Using this method, it became clear that the VI is more structurally diverse in its origin than the VL and VM. Clin. Anat. 30:98–105, 2017.

Key words: quadriceps femoris; vastus intermedius; muscle origin; anatomical variation

INTRODUCTION

The quadriceps femoris (QF), a major extensor of the knee joint, is crucial for human movements such as standing, walking, and running (Bleck, 1979; Montgomery et al., 1994; Blazevich et al., 2006). It comprises 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 originates only from the small area of bony pelvis (the inferior anterior iliac spine). In contrast, the VM, VL, and VI arise from the femur, not the pelvis. The VM mainly arises from the medial lip (ML) of the linea aspera, the VL from the lateral lip (LL) of the linea aspera and the anterior aspect of the lateral intermuscular septum (LIS; Fig. 1A). The medial edge of the LIS is attached to the LL, so the two attachment regions of the VL are continuous.

Descriptions of the origins of the RF, VL, and VM are consistent among anatomy textbooks, as described above. However, descriptions of the origin of the VI differ among textbooks (as summarized in

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Received 24 June 2016; Revised 29 August 2016; Accepted 31 August 2016
Published online 31 October 2016 in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/ca.22791

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Some state that the VI originates from both 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 do not include the LIS as an attachment site (Henle, 1855; Gegenbaur, 1890; Davis-Colley and Bardeen, 1907; Frohse and Fränkel, 1913; Staubesand, 1985).

Recent anatomical studies of the QF have frequently distinguished the longitudinal and oblique parts of the VL (Becker et al., 2009). However, because these two parts and their relationships to each other have not been clearly defined (Vieira, 2011), the muscle belly 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 this study, to clarify the origin structures of the three vastus muscles of the QF, particularly the VI, we analyzed isolated QF specimens. The isolated muscle specimen is a useful tool for analyzing the structure of an individual muscle, which can be difficult to observe by routine dissection.

MATERIALS AND METHODS

Source of Cadavers

All cadavers were from persons who had donated their bodies for medical education and research to Juntendo University School of Medicine. Prior to donation, written consent was obtained from the individuals and families. The protocol for the present research project was approved by the Ethics Committee of Juntendo University School of Medicine (approval No. 2014138).

Thirty-three right legs 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 Juntendo University School of Medicine. In our dissection protocol for medical students, the left legs are dissected to observe the bones and ligaments, so the muscles, nerves, and vasculature are more or less completely destroyed. We therefore used only the right legs, where there was no serious structural damage to the muscles.

We excluded cadavers that exhibited significant pathological alterations in the muscles (such as muscular dystrophy, fatty degeneration, and large intramuscular hematomas), traumatic lesions, and operation scars.

Isolation of Muscle Specimens

The femoral muscles with fascia lata were exposed according to routine procedures, and the 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 the QF from the skeleton as follows (Figs. 1A–1D). First, the proximal end of the RF was detached from the pelvis, and the distal tendon of the QF together with the articular capsule of the knee joint was cut around the superior and lateral margins of the patella and horizontally on both sides of the patella at the level of the articular space. The distal end of the QF was then lifted upwards, and its proximal attachment together with the 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 surfaces of all specimens were cleaned by removing soft connective tissue and fat.

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

| 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                            |
| Cunningham's Textbook of Anatomy  | Romanes (1972)                    | VL                                 | VI                            |
| Clinically Oriented Anatomy       | Moore (1980)                      | VL                                 | VI                            |
| Anatomy for Surgeons (3rd ed.)    | Hollinshead (1982)                | VL                                 | VI                            |
| Morris's Human Anatomy (4th ed.)  | Davis-Colley and Bardeen (1907)   | VL                                 | VI                            |
| Handbuch der Muskellehre des      | Henle (1855)                      | VL                                 | Anterior                      |
| Menschen (1st ed.)                |                                   |                                    |                               |
| Lehrbuch der Anatomie des         | Gegenbaur (1890)                  | VL                                 | Anterior                      |
| Menschen (4th ed.)                |                                   |                                    |                               |
| Anatomie des Menschen (3rd ed.)   | Braus and Elze (1954)             | VI                                 | Anterior                      |
| Benninghoff's Makroskopische und  | Staubesand (1985)                 |                                    |                               |
| Mikroskopische Anatomie des       |                                   |                                    |                               |
| Menschen (14th ed.)               |                                   |                                    |                               |
| Handbuch der Anatomie des         | Frohse and Frankel (1913)         | VL                                 | Anterior                      |
| Menschen (1st ed.)                |                                   |                                    |                               |
| Traité d’Anatomie Humaine         | Testut (1899)                     | VL                                 | Anterior                      |
| (4th ed.)                         |                                   |                                    |                               |
| Traité d’Anatomie Humaine         | Poirier (1893)                    | VL                                 | Anterior                      |
| (1st ed.)                         |                                   |                                    |                               |

Abbreviations: LIS, lateral intermuscular septum; VI, vastus intermedius; VL, vastus lateralis.
The direction of the fibers of the vastus muscles was clear in the isolated specimens. This direction revealed the boundaries among the origin domains of these 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. 1). The QF was a massive muscle almost completely wrapping the femoral shaft (Figs. 1A, 1B, and 20), except for the region between the lateral and MLs of the linea aspera (Figs. 1B″ and 1C″).

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 LL (Fig. 1C″), while the lateral end continued to 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 ML (Figs. 1B″ and 1C″).

Fig. 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 expose the VI further. 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 has 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 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. [Color figure can be viewed at wileyonlinelibrary.com]
To isolate the QF together with the LIS from the femur (Fig. 2), 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 isolate. The structures of the VL, VM, and VI were very structurally diverse. The origin domain of the VI was subdivided into contacting and non-contacting types on the basis of 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 attached muscularly to the anterior and lateral surface of the femoral shaft. The origin domain of the VI adjoined that of the VL at the LL 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 noncontacting 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 LL. 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. [Color figure can be viewed at wileyonlinelibrary.com]
Separate from those structures owing to the dense connections. In contrast, the non-origin domain had indirect contact with the femur via loose connective tissue containing adipose tissue, and was easily detached. In each of the isolated specimens, we found the articularis genus on its deep surface and removed it from the VI.

**Origins of the VL and VM**

The VL possessed a stout membranous origin tendon on the superficial surface arising from the superior portion of the femur including the greater trochanter (Figs. 1C and 2A1–2). On the deep surface of each specimen, the origin domain of the VL was found in the lateral region and divided into two subdomains, one for the VL-L arising from both the femur and the superior part of the LIS, and the other for the VL-O arising from the inferior part of the LIS (Figs. 2C1–3). The origin domain of the VL-L was further demarcated at its attachment to the LL of the linea aspera into a superomedial part arising from the femur and an inferolateral part arising from the LIS (arrowheads in Figs. 2C1–3). The superomedial part of the VL-L origin domain arose from the superior portion of the femur containing the anterior aspect of the greater trochanter, the small area of the gluteal tuberosity, and the superior one-quarter of the LL (dark green area in Figs. 2C2–3). In contrast, the inferolateral part of VL-L domain arose musculary from the superior one-quarter of the anterior aspect of the LIS without tendon formation (light green area in Figs. 2C2–3). The origin domain of the VL-O attached musculary to the inferior three-quarters of the anterior aspect of the LIS, also without tendon formation (blue area in Figs. 2C2–3). In all of the specimens examined, the origin domains of the VL-L and VL-O were continuous and formed a single domain that 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 the femur (solid circles in Figs. 2A1–2). On the deep surface of each specimen, the origin domain of the VM was found along the medial edge, arising solely from the posterior region of the femur containing the intertrochanteric line and the ML of the linea aspera (purple area in Figs. 1C2 and 2C2–3). It did not arise from the intermuscular septum, since the medial part of the intermuscular space was formed by loose connective tissue containing blood vessels and nerves, practically lacking a fascial intermuscular septum. In each of the specimens examined, the origin domain of the VM was almost constant in shape and location (Fig. 3).

**Origin of the VI**

The VI typically arose musculary from the anterior and lateral aspect of the femur without an origin tendon (Figs. 1C and 2B1–2). On the deep surface of each specimen, the origin domain of the VI was found in the superior two-thirds of the central region arising from the femur containing the intertrochanteric line and the ML of the linea aspera (purple area in Figs. 1C2 and 2C2–3). It did not arise from the intermuscular septum, since the medial part of the intermuscular space was formed by loose connective tissue containing blood vessels and nerves, practically lacking a fascial intermuscular septum. In each of the specimens examined, the origin domain of the VI was almost constant in shape and location (Fig. 3). In particular, the topographical variation of the origin domain of the VI was remarkable in relation to the origin domain of the VL, either contacting the LL of the linea aspera forming a continuous region with that of the VL (Figs. 3A1–2 and 4A1–2), or separated from it forming an isolated region (Figs. 3B1–10 and 4B1–2). Thus, we classified the origin domain of the VI into contacting...
DISCUSSION

Anatomical analysis of the three vastus muscles can be difficult owing to their broad attachments to the femur, which make them difficult to manipulate in embalmed cadavers. In the present study, we analyzed isolated QF specimens, which allow for manipulation without restriction by the skeleton and enable the deep surfaces of the muscles to be observed directly. Using this method, we determined the origins of the three vastus muscles precisely and found wide structural diversity in the VI.

The three-dimensional relationship between muscles and skeletons is crucial for understanding muscle function, but it is completely disrupted in isolated muscle specimens. In situ muscle specimens that remain attached to the skeletons have an advantage in the anatomical analysis of muscle function. Therefore, to understand the structure and function of a muscle comprehensively, analysis of both in situ and isolated specimens is needed.

In earlier 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 describe 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 do not mention the origin of the VI from the LIS (Henle, 1855; Gegenbaur, 1890; Davis-Colley and Bardeen, 1907; Frohse and Frankel, 1913; Staubesand, 1985).

In this study using isolated muscle specimens, we confirmed that the VI originated only from the femoral shaft, and not from the LIS as described in the latter group of textbooks.

We also found that the origin domains of the VL and VM were relatively constant in shape and location but the VI was structurally very diverse, an observation not previously reported to the best of our knowledge. There are several reasons why the structural diversity of the VI has not been recognized. One reason is methodological. 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 involving the hip joint.

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, the VL and VI could not be distinguished and the extensor apparatus of the knee could be regarded as possessing only three muscle heads (Frohse and Frankel, 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 a “triceps femoris,” as mentioned by Frohse and Frankel (1913). However, the QF associated with the noncontacting type of VI clearly exhibited four separate muscle heads, as usually stated.

The structural diversity of the VI origin domain observed in this study was simply correlated with the difference of muscle mass of the VI. The muscle belly of the VI had constant location and morphology, attaching to the anterior aspect of the femoral shaft, and decreasing in thickness from the anterior to the lateral parts. The contacting type of VI with larger origin domain implies extensive development and lateral expansion of the VI, while the noncontacting type with smaller origin domain implies poor development and limited VI mass. We found no sign of a difference in developmental origin of the VI from the muscle morphology, although we could not analyze the innervation of the muscle owing to the limitation imposed by studying isolated muscle specimens.

The functional contribution of the VI is estimated to be the largest among the three vastus muscles of the QF (Zhang et al., 2003). Recent investigators have tried to measure the electromyographic activity of the VI by surface and needle electrodes, on the assumption that the inferolateral part of the QF would represent the VI as suggested by magnetic resonance imaging (Watanabe and Akima, 2009; Saito and Akima, 2015). However, this study revealed beyond doubt that this muscular part represented the VL-O, not the VI. Furthermore, in view of the conspicuous variation in expansion of the origin domain and muscle mass of the VI, it does not seem feasible that the major functional role of the VI in knee flexion could be determined in any simple way. Concerning clinical implications, the VI does not become a specific site of traumatic injuries or an object of surgical intervention, except in rare cases such as VI tendon rupture (Thompson et al., 2008; Cetinkaya et al., 2015) or trans-VI transfer of a pedicled thigh flap (Batdorf et al., 2013), because of its deep location in the thigh covered by the other vastus muscles.

In future studies, we need to determine the morphology of the VI and to examine how its structural diversity influences the movement of the knee joint and the stability of the patellofemoral joint. The first challenge is to establish the three-dimensional
morphism of the three vastus muscles in healthy living individuals by magnetic resonance imaging and reconstruction.

In conclusion, the isolated muscle specimen is a useful tool for analyzing individual muscle structures. Using this method, it became clear that the VI is much more structurally diverse in its origin than the VL and VM.

ACKNOWLEDGMENTS

The authors wish to thank Dr. Tomomi Nakamura, Mr. Taro Okamura, and Mr. Koichi Ikarashi for their skillful technical assistance. They are also grateful to the individuals who donated their bodies to Juntendo University School of Medicine. This article was made possible by the selfless gifts from these donors.

CONFLICTS OF INTEREST

The authors have no conflicts of interest to declare.

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