

REVIEW

Do the Vastus Medialis Obliquus and Vastus Medialis Longus Really Exist? A Systematic Review

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There remains controversy over whether the vastus medialis (VM) is a single anatomical structure or whether it is composed of two separate portions, the vastus medialis longus (VML) proximally and the vastus medialis obliquus (VMO) distally. The objective of this study was to assess the evidence base of investigations into muscle fiber orientation, presence of a fibrofascial plane, and the innervation of the VM in human cadaver specimens and subjects. In addition to a hand search of specialist journals, an electronic search of AMED, British Nursing Index, CINAHL, the Cochrane database, EMBASE, ovid Medline, Pubmed, and Zetoc were performed from their inception to September 2008. All human subject papers assessing VM fiber orientation, presence of a fibrofascial plane, and the innervation of the VM were reviewed. Twenty-six papers, assessing 699 healthy knees, and 591 specimens with patellofemoral dysfunction were reviewed. The majority of nonpathological and pathological cases presented with a substantial alteration in fiber alignment seen between proximal and distal muscle portions of VM. Both cohorts presented with either one or two nerve branches to the VM. A fibrofascial plane dividing these two muscles was seen in a small proportion of both pathological and nonpathological knees. There was, however, insufficient good quality evidence to state whether the VM is composed of two separate components, the proximal VML and the distal VMO. Further study is recommended to evaluate the pathophysiological implications of such findings and to assess whether these correlate to functional electromyographic findings between the VML and VMO muscles. Clin. Anat. 22:183–199, 2009. © 2008 Wiley-Liss, Inc.

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INTRODUCTION

Debate has existed for decades as to whether the vastus medialis (VM) is a single anatomical structure or composed of two distinct muscles, the vastus medialis obliquus (VMO) and the vastus medialis longus (VML) (Travnik et al., 1995; Speakman and Weisberg, 1977; Barbaix and Pouders, 2005). The VMO is suggested to arise from the adductor magnus muscle and, to a lesser degree, from the tendon of the adductor longus muscle, and inserts into the medial border of the patella, between one-third and one-half from the proximal pole (Koskinen and

Kujala, 1992; Herrington, 1998; Grelsamer, 2000; Phornphutkul et al., 2007). The VML is suggested to originate from the medial lip of the linea aspera and

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the medial intramuscular septum and insets into the medial margin and anterior surface of an aponeurosis, which merges with the quadriceps tendon (Javadpour et al., 1991; Travnik et al., 1995). Muscle fiber alignment is reported as different between these two muscles, becoming increasingly oblique distally (Lieb and Perry, 1968; Terry, 1989; Amis and Farahmand, 1996).

Anatomists and surgeons have cited a number of factors to distinguish the VM as being two independent muscles (Salmons, 1995; Hubbard et al., 1997). Observations of a change in fiber alignment along the VM to the patella and patellar aponeurosis may create two distinct lines of action (Weinstabl et al., 1989). The presence of a fascial plane dividing the VMO and the VML may indicate a structural basis for the division of the VM into two discrete components (Javadpour et al., 1991; Travnik et al., 1995). Furthermore, a specific innervation to the VML and VMO muscles may theoretically allow the VML and VMO to exhibit different contraction onset timings (Lieb and Perry, 1971; Terry, 1989; Glenn and Samojla, 2002; Jojima et al., 2004). These factors have provided some evidence to hypothesize that the VMO and VML are separate muscles, citing that muscles with different anatomical architecture exhibit different functional roles (Blazevich et al., 2006). Consequently, it has been hypothesized that the VMO is purported to act more as a stabilizer to lateral patellar translation, whereas the VML may contribute to a greater extent in knee extension with the other vastii muscles compared with VMO (Speakman and Weisberg, 1977; Bennett et al., 1993; Salzman et al., 1993; Elias et al., 2002). For this reason, the retraining and strengthening of the VMO through physiotherapy is regarded to be important in the management of anterior knee pain and patellar instability (Sakai et al., 2000; McConnell, 2002, 2007).

Conversely, other observers have suggested that these muscles are not separate, blending together to form the distal VM, and should be considered as a single anatomical structure (Nozic et al., 1997; Barbaix and Pouders, 2005). As the VML and VMO are positioned in series, any force developed by the proximal VML must be transmitted to the distal VMO. This questions the notion that the VMO and VML can be independent muscles (Nozic et al., 1997; Jojima et al., 2004; Peeler et al., 2005) and may account for why electromyographic (EMG) studies have been unable to show a substantial isolated contraction of the VMO from the VML (Reynolds et al., 1983; Souza and Gross, 1991; Makhous et al., 2004; Rainoldi et al., in press). Other authors have questioned the frequency of an abrupt change in muscle fiber orientation and innervation along the length of the VM, suggesting that a fibrofascial plane is an anatomical exception (Galtier et al., 1995; Barbaix and Pouders, 2005).

In recognition of these conflicting views, the purpose of this study, through critically evaluating the available literature, was to investigate whether the VMO and VML muscles should be considered distinct or as one anatomical structure, in cases with or with-

out patellofemoral or tibiofemoral joint pathology. We specifically sought to determine the following: (1) fiber alignment within the VM, (2) the presence of a fascial plane, and (3) the innervation of the distal VM.

METHODOLOGY

Eligibility Criteria

All full-text papers assessing vastus medialis muscle fiber orientation, presence of VM fascial plane, or assessing innervation along the entire length of the VM through cadaver dissection, magnetic resonance imaging, or ultrasonography were included. Animal studies were excluded. Both asymptomatic and symptomatic knees or cadaver specimens, with or without pathological joint changes, were included in this systematic review.

Search Strategy

A search was conducted of the electronic databases AMED, British Nursing Index, CINAHL, the Cochrane database, EMBASE, Ovid Medline, Pubmed, and Zetoc from their inception to September 2008. The key terms used were as follows: "vastus medialis," "vastus medialis obliquus," "vastus medialis oblique," "vastus medialis longus," "anatomy," and "cadaver." These broad search terms were employed in an attempt to limit the omission of any relevant publications. A hand search was also conducted of Knee Surgery Sports Traumatology Arthroscopy (1993–September 2008), the Knee (1994–September 2008), the British and American editions of the *Journal of Bone and Joint Surgery* (1988–September 2008), *Journal of Anatomy* (1988–September 2008), *Clinical Anatomy* (1988–September 2008), *Physiotherapy* (1988–September 2008), *Physical Therapy* (1988–September 2008), and the *Australian Journal of Physiotherapy* (1988–September 2008). A search of unpublished or gray literature was undertaken using the databases SIGLE (System for Information on Grey Literature in Europe), the National Technical Information Service, the National Research Register (UK), the British Library's Integrated Catalogue, and Current Controlled Trials database for recently completed trials.

Two investigators (T.S., R.N.) independently assessed all identified titles and abstracts. Full manuscripts were ordered of those citations, which adhered to the eligibility criteria or where it was unclear whether the paper could be relevant. The reference lists from each full manuscript were scrutinized. Each full text was evaluated against the eligibility criteria by the two reviewers. Where disagreement arose, and a census was reached through discussion. The two investigators were not blinded to either source or author of each citation. The corresponding author of each paper included in the review was contacted. They were consulted as to any additional citations that may address the research question.

Data Abstraction and Critical Appraisal

Data were extracted from each included study onto a spreadsheet by a single investigator (T.S.). This was verified by a second investigator (D.H.). This spreadsheet tabulated the following: author names and publication date, sample size, subject/specimen characteristics including pathology, specimen age, gender, method of dissection, method and measurements recorded, results, and relevant methodological limitations. Two reviewers (T.S./R.N.) critically appraised all studies included in the final review using the appraisal tool presented in Table 5. This was developed and based on the CASP guidelines (CASP, 2007) and that of a previously used appraisal tool (Minns Lowe et al., 2007). If disagreement arose from this assessment, it was resolved through discussion.

Data Synthesis

A systematic review requires the identification, appraisal, selection, and synthesis of all research evidence relevant to a specific research question (Petrie and Sabin, 2000). It should use an objective, clearly defined, a transparent approach for research gathering, and synthesis in an unbiased way (Polgar and Thomas, 2000). A meta-analysis may then be undertaken to integrate the quantitative findings from two or more independent studies. To perform this statistical analysis, the data extracted from the studies are required to be comparable or homogeneous (Song et al., 2000).

After scrutinizing the initial search strategy results, we concluded that there were insufficient data on specimen characteristics, such as gender, age, or pathological history, or on data collection methods, to ensure that the studies included in this systematic review did not present with substantial heterogeneity. As a result, it was thought inappropriate to perform a meta-analysis (Rothstein et al., 2005). Therefore, we aimed to answer this study's research question using a systematic review approach.

RESULTS

The results of the search strategy are illustrated in Figure 1. The search yielded 1,093 articles. Of these, 26 studies adhered to the eligibility criteria. A large number of studies were excluded as they were related to the surgical or physiotherapeutic management of knee pathology, a physiological and electromyographic analysis of the quadriceps complex, or had investigated animals. Three studies were excluded because of the replication of data. The same cohort's data on the anatomical parameters of interest for this review were presented in Hubbard et al. (1997, 1998), as well as in Scharf (1984), Scharf et al. (1985), and Weinstabl et al.'s (1989) publications. The most recent publications of each series were chosen for inclusion in this review. The 26 studies, which

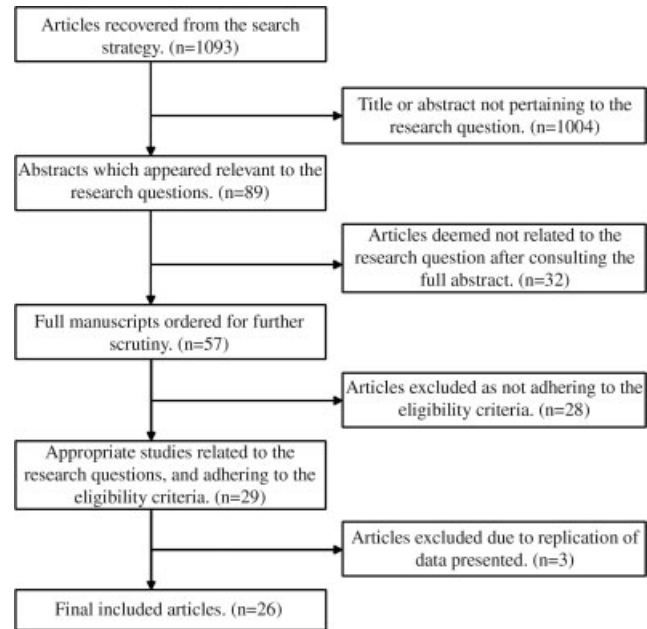


Fig. 1. QUORUM chart.

were finally included in this systematic review, are summarized in Table 1.

Subjects Characteristics

The 26 papers included 807 cadavers of 1,047 knees and 210 subjects of 240 knees. Altogether 430 males and 443 females were assessed, whereas 11 papers did not document the gender of their assessed knees. Age ranges varied from 8 to 100 with a mean age of 66.3 years. Mean age and range values were not documented in 14 papers. Height and weight measurements were documented in three studies. Mean height was 164.4 cm and mean weight was 73.7 kg from these studies. Cadaver specimens with no observable patellofemoral joint injury or damage were assessed in 13 studies, 9 studies did not acknowledge any history or observed patellofemoral joint injury, whereas degenerative patellofemoral joint damage was noted in 4 studies of 581 knees, and 1 study assessed 10 knees of patellar instability patients. The methods of assessing the VM was performed radiologically and through dissection in two studies, dissection alone were performed in 23 studies, whereas solely radiological evaluation was performed in one study. Radiologically, magnetic resonance imagery was adopted in two studies, and computed tomography was used in one study.

The results of the papers assessing healthy, asymptomatic knees and cadavers with no observable patellofemoral joint changes have been analyzed and assessed separately to those of knees, which presented with pathologies such as instability and degenerative changes. These are discussed later.

TABLE 1. Summary of the Papers Included in This Systematic Review

Study	Andrikoula et al. (2006)
Number	10 cadavers (10 knees)
Specimens/Subjects	
Pathology	No observable bony abnormality or degenerative disease.
Subject/Specimen characteristic	6 right, 4 left, 3 female, 7 male, mean age 55 years.
Dissection technique	Dissection of skin and subcutaneous tissue over anterior aspect of knee from superficial fascia. Each layer was incised longitudinally in the midsagittal plane and the separation of the layer was extended proximally, distally, medially, and laterally.
Imaging technique	Not assessed.
Measurement recorded	Angle between the rectus femoris tendon and distal VM measured with a goniometer. Observation of VM attachment to patella and surrounding nerves.
Investigators	Not documented.
Study	Bennett et al. (1993)
Number	40 cadavers (40 intact knees)
Specimens/Subjects	
Pathology	No disruption of the muscular anatomy at the knee or hip.
Subject/Specimen characteristic	17 females, 23 males, aged 52–96
Dissection technique	Cadaver supine, skin, and subcutaneous fat removed at the knee and ASIS. Dissection to allow complete visualization of fiber alignment of the VMO and VLO.
Imaging technique	Not assessed.
Measurement recorded	Angle of insertion of the VMO and VLO terminal fibers orientation to the longitudinal axis of the patella were measured in a uniplanar fashion using a goniometer along each muscle belly and the longitudinal axis of the patella. Fiber alignments of the proximal VM is suggestive of VML.
Investigators	Not documented.
Study	Bose et al. (1980)
Number	17 cadavers (34 knees)
Specimens/Subjects	10 patients with recurrent dislocation of patella (10 knees)
Pathology	Cadaver—not documented
Subject/Specimen characteristic	Patients—Recurrent patellar dislocation
Dissection technique	Not documented.
Imaging technique	Not documented.
Measurement recorded	Distance between lower margin of VMO and the adductor tubercle was measured. Observation of muscle attachments and fiber alignments of VM and insertion of VMO onto patella.
Investigators	Not documented.
Study	Conlan et al. (1993)
Number	8 previously dissected cadaveric specimens (8 knees)
Specimens/Subjects	25 intact cadaveric knees (19 AKA, 6 cadavers specimens)
Pathology	No data on previous lesions of the knee.
Subject/Specimen characteristic	43–89 years.
Dissection technique	Removal of skin, lateral retinacular release, and the specimens mounted horizontally, with the lateral side up, and in full extension in a universal testing machine. Dissection proximal to distal isolating the vastus medialis obliquus fascia.
Imaging technique	Not assessed.
Measurement recorded	Orientation of the vastus medialis. Point of attachment of VMO onto patella.
Investigators	Not documented.
Study	Farahmand et al. (1998)
Number	12 cadavers (12 knees)
Specimens/Subjects	
Pathology	No history of knee surgery or disease.
Subject/Specimen characteristic	Individual ages documented, no mean or range. 8 males, 4 females.
Dissection technique	Skin and subcutaneous fat removed, sartorius, tensor fascia lata, and iliotibial tract cut to access quadriceps insertions and origins.
Imaging technique	Not assessed.
Measurement recorded	Muscle fiber orientation in relation to the vertical axis of the patellar and in the sagittal plane relative to the femoral axis using a goniometer.
Investigators	Not documented.

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TABLE 1. Summary of the Papers Included in This Systematic Review (Continued)

Study	Galtier et al. (1995)
Number	22 cadavers (44 knees)
Specimens/Subjects	
Pathology	No observable knee surgery or knee pathology in life but 41 knees (21 cadavers) presented with cartilage ulceration or mild degenerative changes to the patellofemoral joint.
Subject/Specimen characteristic	19 prepared, 3 fresh cadavers. Age mean 79 (67–94). 10 female, 12 male.
Dissection technique	Longitudinal section from ASIS to patellar. Upper transverse section from ASIS to pubic symphysis. Lower transverse section tangential to apex of patellar. Muscular dissection performed from superficial to deep, level by level. Femoral nerve dissected.
Imaging technique	Not assessed.
Measurement recorded	Observation from fascia planes or muscle component separating VM fiber alignment. Examination of patellofemoral joint cartilage integrity and its location on the patella was classified as no lesion; cartilage ulceration (arthrosis) or velvety degeneration without ulceration or osteophytosis, compatible with ageing. Location and branches of the femoral nerve along the length of VM.
Investigators	Not documented.
Study	Glenn and Samojla (2002)
Number	6 cadavers (6 knees)
Specimens/Subjects	
Pathology	Not documented.
Subject/Specimen characteristic	2 females, 4 males. Ages unknown. Caucasian.
Dissection technique	Quadriceps exposed after removal of skin and fascia lata. A dissection performed as that of Thiranagama (1990). Regions of insertion and origin of muscles identified and boundaries of each vastii head demarcated. Muscles were isolated by dissection and fascia removed.
Imaging technique	Not assessed.
Measurement recorded	Observation of origin and insertion of each vastii muscle, structure of aponeuroses and tendons recorded.
Investigators	Not documented.
Study	Holt et al. (2008)
Number	65 knee (MRI studies)
Specimens/Subjects	18 cadavers (18 knees)
Pathology	MRI—pathology not related to extensor mechanism patients Dissection—not documented.
Subject/Specimen characteristic	MRI—26 female, 39 male; 35 left, 30 right knees. Cadaver females 10, males 8. 11 left, 7 right knees.
Dissection technique	VMO completely exposed.
Imaging technique	MRI with 3 mm slices from axial, sagittal and coronal sequences.
Measurement recorded	On axial MRI, the lowest slice of the insertion for VMO into the patellar tendon was identified. The patella length was assessed on sagittal sequence. The distal VMO insertion was assessed as a percentage of the patellar length. Cadaver assessment, length of patella measured. Most distal point of insertion for VMO was identified. 3 measurements taken each time and mean value calculated. Point at VMO insertion was expressed as a percentage of patellar height. VMO fiber alignment was assessed with goniometer.
Investigators	Each scan assessed by 2 musculoskeletal radiologists. Dissection performed by 5 potential examiners.
Study	Hubbard et al. (1998)
Number	229 cadavers (374 knees): 304 previously dissected, 70 intact.
Specimens/Subjects	
Pathology	No PFJD cartilage deterioration in 91 cases, mild deterioration in 125, extensive cartilage deterioration in 96 and exposure of cortical bone and/or joint destruction evidence in 62 cases.
Subject/Specimen characteristic	177 males, 197 females, Age range 39–100, means 76.7 ± 10.4 .
Dissection technique	304 dissected previously from the depth of the deep layer of the superficial fascia exposing muscle, 70 were intact and were dissected by one anatomist, exposing anterior and medial thigh from ASIS to tibial tubercle. All components of QF were cleansed of fatty and connective tissue. Sharp and blunt dissection techniques were both used.
Imaging technique	Not assessed.
Measurement recorded	Proximal and distal VM fiber angulation measured with standard goniometers with long axis of femur as reference point of measure. Proximal VM taken from fibers lying closest to the shaft of femur, distal VM fibers measured from most distal point of muscle. Presence of fascial plane measured in accordance to Lieb and Perry (1968).
Investigators	2 investigators assessed fiber alignment and presence of fascial plane. ICC for intertester reliability assessed as 0.90 or above.

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TABLE 1. Summary of the Papers Included in This Systematic Review (Continued)

Study	Javadpour et al. (1991)
Number	15 cadavers (15 knees)
Specimens/Subjects	
Pathology	Not documented.
Subject/Specimen characteristic	7 left, 8 right limbs.
Dissection technique	Not documented.
Imaging technique	Not assessed.
Measurement recorded	Observation of fascial plane between VMO and VML and innervation of VM. Origin and insertion of VML and VMO determined. Fiber alignment.
Investigators	Not documented.
Study	Jojima et al. (2004)
Number	10 cadavers (10 knees)
Specimens/Subjects	3 cadavers (3 knees) with TKR prosthesis remaining.
Pathology	No observable osteoarthritic changes in cadavers.
Subject/Specimen characteristic	Average age of prosthesis in 3 retrieved TKR was 5.7 years.
Dissection technique	No other demographics documented.
	Skin and subcutaneous tissues removed. Nerve supply of VM dissected from level of the femoral head to the gross neuromuscular junction. Nerve fibers then dissected into the body of VM and traced to the point of entry into the muscle fascicle.
Imaging technique	Not assessed.
Measurement recorded	Observation and tracing of the innervation to the VM.
Investigators	Not documented.
Study	Lefebvre et al. (2006)
Number	22 cadavers (39 knees) including 1 fetus.
Specimens/Subjects	
Pathology	No observable knee problems or knee surgery.
Subject/Specimen characteristic	Not documented.
Dissection technique	Longitudinal section from ASIS to patella, completed with upper and lower transverse sections. Muscle dissection performed level by level from superficial to deep with dissection of the femoral nerve.
Imaging technique	Not assessed.
Measurement recorded	Presence of fascial plane. Observation of fiber alignment. Location of fiber attachment onto the patella. Dissection of the femoral nerve undertaken and its branches to the VM performed for observation.
Investigators	Not documented.
Study	Lieb and Perry (1968)
Number	6 cadavers (6 knees)
Specimens/Subjects	
Pathology	No evidence of surgery or other knee problems during life.
Subject/Specimen characteristic	Not documented.
Dissection technique	Not documented.
Imaging technique	Not assessed.
Measurement recorded	VM fiber alignment in relation to the femoral axis. Dissection and observation of the innervation and fascial plane along the length of VM.
Investigators	Not documented.
Study	Nozic et al. (1997)
Number	50 cadavers (50 knees)
Specimens/Subjects	
Pathology	No evidence of gross musculoskeletal pathology such as severe osteoarthritis of the knee joint.
Subject/Specimen characteristic	Mean age 61 (SD21) ranging from 16 to 91.
Dissection technique	Full dissection of left thigh.
Imaging technique	Not assessed.
Measurement recorded	Muscle fiber alignment of VMO and VML using the femoral axis using ASIS and midpoints width and length of the patella. Length of muscle attachment of VL onto the superomedial border of the patella measured using vernier callipers. VMO determined as the fibers attached on the patellar, VML defined as fibers passing through the midpoint of the femoral axis line. Observation of nerve supply of VM with an examination of all branches to the muscle along its entire length. Fascial plane between the more longitudinal and more oblique fibers was assessed by cutting through the muscle belly perpendicularly to the direction of the fibers at 3 arbitrary distances 3 cm, 6 cm, 9 cm above the midpoint of its insertion into the superomedial border of the patella. All branches of the femoral nerve were dissected along the VM.
Investigators	Dissection performed by second year medical students. One assessor measured all data with good agreement between assessments with a SEM 0.87 and 0.91 for VML and VMO measurements, respectively.

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TABLE 1. Summary of the Papers Included in This Systematic Review (Continued)

Study	Ono et al. (2005)
Number	1 cadaver (2 knees).
Specimens/Subjects	
Pathology	No observed evidence of knee injury.
Subject/Specimen characteristic	Male, age not specified. No evidence of knee surgery.
Dissection technique	Exposed thigh and leg from the level of ASIS to TT, with the thigh dissected to the depth of the quadriceps muscles.
Imaging technique	Not assessed.
Measurement recorded	Observation from an areolar fascial plane and femoral nerve distribution along the length of VM. Muscle fiber angulation of proximal (defined as fibers lying most proximal to shaft of femur) and distal (defined as the most distal part of muscle) VM measured with a goniometer using the femoral axis as a reference point.
Investigators	Not documented.
Study	Özer et al. (2004)
Number	10 cadavers (20 knees)
Specimens/Subjects	
Pathology	Not documented.
Subject/Specimen characteristic	4 females, 6 males. Mean age 39.6 years (17–68 years).
Dissection technique	Incision extending from below the middle portion of the inguinal ligament to the medial aspect of the knee. Posterior division of the femoral nerve innervating the VM were exposed. Saphenous nerve also identified and traced.
Imaging technique	Not assessed.
Measurement recorded	Observation of the path of the femoral nerve and any nerve innervating VM.
Investigators	Not documented.
Study	Pagnano et al. (2006)
Number	100 TKA patients
Specimens/Subjects	45 cadavers (45 knees)
Pathology	5 healthy volunteers knees for MRI TKA—Degenerative arthritis knees.
Subject/Specimen characteristic	Cadavers—no evidence of degenerative arthritis. TKA—65 women, 35 males aged 67 (range 42–88 years). Cadaver—20 females, 25 males, mean age 72 (range 55–89 years).
Dissection technique	MRI—1 female, 4 males, mean age 33 years (24–44) years. TKA—Intraoperatively the VMO was exposed.
Imaging technique	Cadavers—not described.
Measurement recorded	High resolution MRI assessed on 5 healthy knees. Insertion point of the VMO on the patella was assessed by tracing the insertion of VMO on inferior border of the muscle, over to the intersection with the medial border of the patella, and assessed as a percentage of patella height. Angle of VMO insertion relative to the femoral axis measured using a goniometer. Length of VMO assessed by measuring in cm the most lateral portion of the muscle to the closest point on the patella.
Investigators	Not documented.
Study	Peeler et al. (2005)
Number	24 cadavers (32 intact knees)
Specimens/Subjects	
Pathology	No history of obvious knee trauma with normal patellar height.
Subject/Specimen characteristic	18 females, 14 males. Mean age 79 ± 12 years; weight 64.26 ± 13.5 kg; height 159 ± 10 cm; BMI 25.54 ± 4.39 .
Dissection technique	Dissection technique was adopted through other studies and a pilot study. Anterior thigh divided into two sections with skin and fat removed. Vertical incision made along the femoral axis, proximal to distal from ASIS to tibial tubercle. Fascia removed and blunt dissection used to separate the different portions and away from adductor and abductor regions. VMO assessed superiorly at VM attachment to quadriceps tendon and inferiorly at VM attachment to patella.
Imaging technique	Not assessed.
Measurement recorded	Muscle fiber alignment at VML and VMO drawn on with colored markers, goniometer measurements of the angle at which each line intersected the femoral and vertical axis. Assessment made of presence of a fascial plane, and for presence of separate VMO innervation by assessing each section of the VM length for its innervation from the femoral nerve.
Investigators	1 anatomist, with experience in dissections of gross anatomy.

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TABLE 1. Summary of the Papers Included in This Systematic Review (Continued)

Study	Peeler and Anderson (2007)
Number	24 cadavers (32 intact knees)
Specimens/Subjects	
Pathology	No history of obvious knee trauma with normal patellar height.
Subject/Specimen characteristic	18 females, 14 males. Mean age 79 ± 12 years
Dissection technique	As described by Peeler et al. (2005).
Imaging technique	Not assessed.
Measurement recorded	Length of VM from inferior section to patellar insertion measured using a tape measure. Fiber alignment measured from the femoral axis to inferior section of the VM using a flexible goniometer.
Investigators	One investigator with over 10 years undergraduate, graduate teaching and dissection experience of gross anatomy.
Study	Raimondo et al. (1998)
Number	21 cadavers (21 knees)
Specimens/Subjects	
Pathology	Not documented.
Subject/Specimen characteristic	16 females, 5 males. Age mean 77 years (ranging 32–102).
Dissection technique	Exposure of the vastus medialis complex with attention made not to disrupt the origin and insertion of the VMO and VML prior to measurement.
Imaging technique	Not assessed.
Measurement recorded	Insertion angle of VMO and VML muscle fibers in respect to the femoral axis using a goniometer. Observation for a fascial plane.
Investigators	Not documented.
Study	Reider et al. (1981)
Number	48 cadavers (48 knees)—26 preserved, 22 fresh, 20 autopsies, 2 amputated.
Specimens/Subjects	
Pathology	Not documented.
Subject/Specimen characteristic	22 female, 26 male. 46 white, 2 black, 4 subjects were more than 80 years old, 15 in their 70s, 15 in their 60 s, 10 in their 50 s, 4 in their 40 s
Dissection technique	Skin and subcutaneous fat removed. Anterior longitudinal incision through the fascia lata extending over the patellar to its inferior aspect. Deep fascia dissected free of the underlying muscle laterally to the intermuscular septum, medially to the adductor magnus muscle, and inferiorly to the apex of the patella.
Imaging technique	Not assessed.
Measurement recorded	Origin and insertion of vastii muscles. Fiber alignment of VMO and VML. Presence of fascial plane between VMO and VML.
Investigators	Not documented.
Study	Scott et al. (1993)
Number	1 cadaver (1 knee)
Specimens/Subjects	
Pathology	CVA
Subject/Specimen characteristic	79 years old; weight 95 kg, height 180 cm.
Dissection technique	Mounted in full extension on a wooden frame.
Imaging technique	MR using 10 mm cross-sectional imagery from ASIS to knee joint.
Measurement recorded	Pennation angle defined as the angle between the line of action of the muscle and the path of fascicle was measured using a goniometer.
Investigators	Not documented.
Study	Thiranagama (1990)
Number	15 cadavers (30 knees)
Specimens/Subjects	
Pathology	Not documented.
Subject/Specimen characteristic	2 female, 13 male. Age range 8–60.
Dissection technique	Not clearly documented.
Imaging technique	Not assessed.
Measurement recorded	Innervation of VM observed from femoral nerve to whole length of VM, with terminal branches traced into the muscle using a hand lens. VM muscle fiber orientation.
Investigators	Not documented.

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TABLE 1. Summary of the Papers Included in This Systematic Review (Continued)

Study	Toumi et al. (2007)
Number	10 cadavers (10 knees)
Specimens/Subjects	
Pathology	Not documented.
Subject/Specimen characteristic	Not documented.
Dissection technique	Skin and superficial fascia surrounding the quadriceps were removed through a longitudinal incision from ASIS to the patella followed by upper and lower transverse cuts.
Imaging technique	Not assessed.
Measurement recorded	Observation of VM fiber alignment and femoral nerve and its branches of VM.
Investigators	Not documented.
Study	Watanabe et al. (2008)
Number	30 patients (60 knees)
Specimens/Subjects	
Pathology	Osteoarthritis undergoing TKA
Subject/Specimen characteristic	10 males, 20 females. Age—60 to 85 years, mean age 74.2 ± 5.1 years, height 154.2 ± 8.3 cm, weight 62.8 ± 10.6 kg; BMI 26.3 ± 2.9 , femorotibial angle $184.4 \pm 6.2^\circ$
Dissection technique	Not assessed
Imaging technique	CT with multiplanar reconstruction (MPR) and 3D-volume rendering (3D-VR) with 0.5 mm slice thickness and 0.5 mm slice increments.
Measurement recorded	VMO fiber angle measured from most distal portion of the muscle belly related to the long axis of the rectus femoris in anteroposterior view on VR as previously described in cadaver goniometer measurements.
	Distal height of VMO insertion calculated as the percentage of the length between the uppermost point of the patellar and the insertion side relative to the total patellar length on the sagittal MRI image through the centre of the patella.
Investigators	One investigator.
Study	Weinstabl et al. (1989)
Number	157 cadavers (157 knees) of which 115 assessed VM
Specimens/Subjects	
Pathology	Not documented.
Subject/Specimen characteristic	Not documented.
Dissection technique	Dissection of 3 levels, superficial within the area of the fascial pane, and following the muscle up from its point of insertion.
Imaging technique	Not assessed.
Measurement recorded	fiber alignment of VM assessed by position thread in direction of fibers and measuring in relation to the femoral axis. Presence of areolar fascial plane, nerve innervation pattern observed.
Investigators	Not documented.

ASIS, anterior superior iliac spine; BMI, body mass index; cm, centimeters; CT, computed tomography; ICC, intra-class coefficient correlation; kg, kilograms; mm, millimeters; MRI, magnetic resonance imagery; PFJD, patellofemoral joint dysfunction; QF, quadriceps femoris; SEM, standard error of mean; TKA, total knee arthroplasty; TKR, total knee replacement; TT, tibial tubercle; VM, vastus medialis; VMO, vastus medialis oblique; VML, vastus medialis longus.

Fiber Orientation

Table 2 outlines the results of fiber alignment. Fiber orientation was assessed in the sagittal plane with respect to the aponeurosis in 10 studies, in the frontal plane with respect to the vertical axis in two, whereas eight studies did not clearly define how they assessed VM fiber orientation.

Of the included papers, 18 studies investigated VMO fiber orientation patterns in 500 knees of 468 cadaver specimens with no observable patellofemoral joint injury or damage. Seventeen papers provided quantified fiber alignment angles on these subjects. These reported that distal VM or VMO fiber orientation ranged from 40° to 77° , with a mean fiber

orientation of 49.9° . Proximal VM or VML fiber orientation ranged from 11.5° to 35° , with a mean fiber orientation of 21.8° . When compared, the mean difference in fiber alignment would, therefore, be 28.1° from proximal to distal VM.

Four studies assessed fiber orientation with knees exhibiting patellofemoral joint degeneration and instability (Bose et al., 1980; Hubbard et al., 1998; Pagnano et al., 2006; Watanabe et al., 2008). As Table 2 illustrates, they reported similar mean VMO and VML fiber orientation values to the studies assessing non-pathological cases. Hubbard et al. (1998) reported that there was no statistically significant difference in VMO fiber orientation and the degree of patellofemoral

TABLE 2. Results of VM Fiber Alignment and Differences Between Proximal and Distal VM Fiber Alignment in Papers Included in This Review

Study	Average VMO fiber alignment (°)	Average VML fiber alignment (°)
Andrikoula et al. (2006)	45.5 ± 8.39	N/D
Bennett et al. (1993)	Female 49.7 ± 6.7 Male 52.2 ± 8.4	Female 33.1 ± 5.79 Male 36.3 ± 6.5
Bose et al. (1980)	Deposition of fibers was either oblique or transverse.	N/D
Conlan et al. (1993)	49 (42–60)	N/D
Farahmand et al. (1998)	47 ± 5 Females 44.8 Males 48.1	15 ± 2 Females 14.5 Males 15.6
Glenn and Samojla (2002)	No sudden change in fiber alignment from VMO to VML.	No sudden change in fiber alignment from VMO to VML.
Holt et al. (2008)	43.0 ± 9.6	N/D
Hubbard et al. (1998) ^a	53.2 ± 6.9	14.6 ± 4.02
Lieb and Perry (1968)	50–55	15–18
Nozic et al. (1997)	52.2 ± 6.2	11.5 ± 3.0
Ono et al. (2005)	Right 40 Left 40	N/D
Pagnano et al. (2006) ^a	OA—50 (range, 46–52) Non-Path—51 (range, 46–55)	N/D
Peeler et al. (2005)	57 ± 6	22 ± 5
Peeler and Anderson (2007)	57 ± 6 Females 56 ± 6 Males 59 ± 5	N/D
Raimondo et al. (1998)	52 ± 2	18 ± 2
Reider et al. (1981)	55°–70°	Less oblique than VMO
Scott et al. (1993)	50	N/D
Thiranagama (1990)	40–55	15–35
Watanabe et al. (2008) ^a	52.9 ± 3.9 (47.0 to 61.5) Female 52.9 ± 3.7 Male 52.6 ± 4.2	N/D
Weinstabl et al. (1989)	48.9 ± 1.0 to 3.5	16.8 ± 0.8 to 1.6

OA, knee presenting with osteoarthritis; Non-Path, knee presenting with no degenerative or pathological changes; N/D, not documented.

^aStudies assessing pathological knees.

joint degeneration ($P = 0.56$). Bose et al. (1980) reported that the deposition of fibers was either oblique or transverse. A transverse pattern would differ in this cohort of patellar instability specimens

when compared with the degenerative and nonpathological cases review.

Three studies compared VMO fiber orientation between male and female nonpathological speci-

TABLE 3. Results of the Presence of Fibrofascial Plane in Studies Included in This Review

Study	Distinct fibrofascial plane in VM (% of cohort)	Distinct fibrofascial plane in VM (case frequency)
Galtier et al. (1995) ^a	0	0/44
Glenn and Samojla (2002)	0	0/6
Hubbard et al. (1998) ^a	21.65	81/374
Javadpour et al. (1991)	100	15/15
Lefebvre et al. (2006)	0	0/39
Lieb and Perry (1968)	17	1/6
Nozic et al. (1997)	2	1/50
Ono et al. (2005)	0	0/2
Peeler et al. (2005)	0	0/32
Reider et al. (1981)	2	1/48
Weinstabl et al. (1989)	50	57/115

^aStudies assessing pathological knees.

TABLE 4. Results of Innervation to VM in Studies Included in This Review

Study	Number of nerve trunks to VM (case frequency)	Number of nerve trunks to VM (%)
Galtier et al. (1995) ^a	20/44	1 in 45
	24/44	2 in 55
Javadpour et al. (1991)	15/15	1 in 100
Jojima et al. (2004)	10/10	1 in 100
Lefebvre et al. (2006)	17/39	1 in 44
	22/39	2 in 56
Lieb and Perry (1968)	5/6	1 in 83
	1/6	2 in 17
Nozic et al. (1997)	50/50	2 in 100
Ono et al. (2005)	2/2	2 in 100
Özer et al. (2004)	20/20	2 in 100
Peeler et al. (2005)	32/32	1 in 100
Thiranagama (1990)	30/30	2 in 100
Toumi et al. (2007)	10/10	2 in 100
Weinstabl et al. (1989)	115/115	1 in 100

^aStudies assessing pathological knees.

mens, whereas Watanabe et al. (2008) assess the difference in gender in a cohort of degenerative knee subjects. These papers, including 84 knees, reported that mean VMO fiber orientation was 53.1° in males and 50.2° in female, whereas the difference in fiber orientation between gender was less in Watanabe et al.'s (2008) 60 knees. Fiber orientation of VML was compared between male and female subjects in two studies, both of nonpathological knees (Bennett et al., 1993; Farahmand et al., 1998). They similarly reported a small difference between the genders of 1.1° in Farahmand et al. (1998) and 3.2° in Bennett et al.'s (1993) study.

Fibrofascial Plane

The presence of a fibrofascial plane was presented in nine studies in cadaver specimens with no observable patellofemoral joint injury or damage (Table 3). Identification of a fibrofascial plane was made by simple observation of dissected specimens.

A fibrofascial plane was not demonstrated in four papers of 79 cases, once in three papers of 104 cases, and in 50 and 100% of cases in Weinstabl et al.'s (1989) 115 specimen and Javadpour et al.'s (1991) 15 specimen samples, respectively. In total, the presence of a fibrofascial plane passing from the superficial to the deep surface of the muscle belly was identified in 75 subjects of 313 cadavers with no observable patellofemoral joint injury or damage, accounting for 24.0% of the cohort reviewed.

Galtier et al. (1995) and Hubbard et al. (1998) assessed for the presence of a fibrofascial plane in the degenerative patellofemoral joints of 418 cadaver specimens. Hubbard et al. (1998) reported the presence of a fibrofascial plane in 22% of cases in their cohort. These authors reported that there was no statistically significant difference between the presence or absence of a fibrofascial plane and the degree of joint degeneration of the patellofemoral

joint ($P = 0.932$). Galtier et al. (1995) reported that a distinct fibrofascial plane was not identifiable in their 44 specimen cohort.

Only Hubbard et al. (1998) assessed whether there was a statistical difference between gender and for the presence of a fibrofascial plane. They reported that there was no significant difference between male and female subjects in respect to the presence of a fibrofascial plane ($P = 0.737$).

Innervation

Table 4 outlines the results assessing VM innervation. The VM's innervation was assessed in all studies by simple observation of the dissected specimens. Innervation was evaluated in 11 studies incorporating 329 knees with no observable patellofemoral joint injury or damage.

A single nerve trunk was identified in seven papers (194 knees or 59.0% of the cohort reviewed), whereas 135 knees demonstrated two nerve trunks accounting for 41.0% of the knees without degenerative changes reviewed. In the cases where two branches were identified, these were identified from the femoral nerve. In such cases, the femoral nerve gave off a short branch that rapidly perforated to the deep layers of the proximal portion of the VM and ramified to three to five smaller branches, which supplied the proximal and middle portion of VM. The second branch identified was a long superficial thin branch, which transversed the subsartorial canal alongside the femoral vessels and supplied the distal part of the VM.

Galtier et al. (1995) assessed the innervation of VM in pathological patellofemoral joint specimens. They reported that in 45% of their pathological cohort one nerve branch was identified, whereas two branches were identified in 55% of their cohort. On further analysis, these differences in innervation were significantly correlated with the degree of

TABLE 5. The Critical Appraisal Checklist Used to Assess the Studies Included in This Review

Criteria											
Focused question	Appropriate design	Population defined	Recruitment methods acknowledged	Sample size defined by power	Study setting described	Outcome measures defined	Dissection method defined	Radiological assessment described	Observers defined	Observer reliability assessed	
Andrikoula et al. (2006)	Y	Y	N/D	N	N	Y	Y	N/D	N	N	
Bennett et al. (1993)	Y	Y	N/D	N	Y	Y	Y	N/D	N	N	
Bose et al. (1980)	Y	N	N/D	N	N	N	N	N/D	N	N	
Conlan et al. (1993)	Y	N	N/D	N	N	N	N	N/D	N	N	
Farahmand et al. (1998)	Y	Y	N/D	N	N	Y	Y	N/D	N	N	
Galtier et al. (1995)	Y	Y	N/D	N	N	Y	Y	N/D	N	N	
Glen and Samojla (2002)	Y	N	N/D	N	N	N	N	N/D	Y	N	
Holt et al. (2008)	Y	N	N	N	N	Y	N	Y	Y	N	
Hubbard et al. (1997)	Y	N	N/D	N	N	N	N	N/D	N	Y	
Javadpour et al. (1991)	Y	Y	N/D	N	N	N	Y	N/D	N	N	
Jojima et al. (2004)	Y	Y	N/D	N	N	Y	Y	N/D	N	N	
Lefebvre et al. (2006)	Y	N	N/D	N	N	N	Y	N/D	N	N	
Lieb and Perry (1968)	Y	Y	N/D	N	N	Y	Y	N/D	N	N	
Nozic et al. (1997)	Y	N	N/D	N	N	Y	N	N/D	N	Y	
Ono et al. (2005)	Y	Y	N/D	N	N	Y	N	N/D	N	Y	
Özer et al. (2004)	Y	N	N/D	N	N	Y	Y	N/D	N	N	
Pagnano et al. (2006)	Y	N	Y	N	N	Y	Y	N	N	N	
Peeler et al. (2005)	Y	Y	N/D	N	N	Y	Y	N/D	Y	N	
Peeler and Anderson (2007)	Y	N	N/D	N	N	Y	Y	N/D	Y	N/D	
Raimando et al. (1998)	N	N	N/D	N	N	Y	N	N/D	N	N	
Reider et al. (1981)	Y	Y	N/D	N	N	N	Y	N/D	N	N	
Scott et al. (1993)	Y	N	N/D	N	N	Y	N	Y	N	N	
Thiranagna (1990)	Y	Y	N/D	N	N	Y	N	N/D	N	N	
Toumi et al. (2007)	Y	N	N/D	N	Y	N	N	N/D	N	N	
Watanabe et al. (2008)	Y	Y	N	N	N	Y	N	Y	N	Y	
Weinstabel et al. (1989)	Y	N	N/D	N	N	N	Y	N/D	N	N	
Multiple observations	Blinding of observer to pathology	Statistical methods described	Variance described	Inferential statistics employed	CI presented	Appropriate interpretation		Generalizability	Relevance to present evidence base	Clinical relevance discussed	
Andrikoula et al. (2006)	N	N	N	N	N	Y	Y	Y	Y	Y	
Bennett et al. (1993)	N	Y	Y	Y	N	Y	Y	Y	Y	Y	
Bose et al. (1980)	N	N	N	N	N	Y	N	N	N	Y	
Conlan et al. (1993)	N	N	N	N	N	Y	N	N	N	Y	
Farahmand et al. (1998)	N	N	Y	Y	N	Y	Y	Y	Y	Y	
Galtier et al. (1995)	N	Y	N	N	N	Y	Y	Y	Y	Y	
Glen and Samojla (2002)	N	Y	Y	N	N	Y	Y	N	Y	Y	
Holt et al. (2008)	N	N	N	N	N	Y	Y	N	Y	Y	
Hubbard et al. (1997)	N	N	N	N	N	Y	Y	N	Y	Y	
Javadpour et al. (1991)	N	N	N	N	N	Y	Y	N	Y	Y	
Jojima et al. (2004)	N	N	Y	Y	N	Y	Y	Y	Y	Y	
Lefebvre et al. (2006)	N	N	N	N	N	N	Y	N	N	N	
Lieb and Perry (1968)	N	N	Y	N	N	Y	Y	Y	Y	Y	
Nozic et al. (1997)	N	Y	N	N	N	Y	Y	N	Y	Y	
Ono et al. (2005)	N	N	Y	N	N	Y	Y	Y	Y	Y	
Özer et al. (2004)	N	N	N	N	N	Y	Y	N	Y	Y	
Pagnano et al. (2006)	N	Y	N	Y	N	Y	Y	N	Y	Y	
Peeler et al. (2005)	N	Y	Y	Y	N	Y	Y	N	Y	Y	

TABLE 5. The Critical Appraisal Checklist Used to Assess the Studies Included in This Review (Continued)

	Criteria									
	Multiple observations	Blinding of observer to pathology	Statistical methods described	Variance described	Inferential statistics employed	CI presented	Appropriate interpretation	Generalizability	Relevance to present evidence base	Clinical relevance discussed
Peeler and Anderson (2007)	N	N	N	N	N	N	Y	N	Y	Y
Raimondo et al. (1998)	N	N	N	Y	Y	N	Y	N	Y	Y
Reider et al. (1981)	Y	N	N	Y	Y	N	Y	N	N	Y
Scott et al. (1993)	N	N	N	N	N	N	Y	N	Y	Y
Thiranagna (1990)	N	N	Y	Y	Y	Y	Y	N	Y	Y
Toumi et al. (2007)	N	N	N	N	N	N	Y	N	Y	Y
Watanabe et al. (2008)	N	N	N	N	N	N	N	Y	N	Y
Weinstabel et al. (1989)	N	N	N	N	N	N	Y	N	Y	Y

Y, yes; N, no; N/D, not documented.

patellofemoral cartilaginous damage. Cartilage ulceration was identified in 90% of specimens, which presented with one nerve branch, when compared with 38%, which exhibited two nerve branches. In 62% of specimens with two nerve branches mild degenerative changes or none were present when compared with only 10% of specimens with one nerve branch. This difference was statistically significant ($P < 0.0004$). These authors also correlated the site of cartilaginous lesion to innervation. They reported that 90% of specimens with one nerve branch presented with isolated lateral patellar facet lesions, whereas those with two branches exhibited diffuse or medial patellofemoral degenerative changes. This difference was statistically significant ($P < 0.0001$).

Similarly, only Galtier et al. (1995) provided data to compare innervation patterns between male and female subjects. Their results suggested little difference between the genders where 58% of males presented with two branches when compared with 50% of females.

Critical Appraisal

The results of the critical appraisal tool are presented in Table 5. This reported that all the studies review incorporated an appropriate methodological design, but five studies did not present a clearly defined research question. The patient and specimen population characteristics were poorly described. Although a number of papers described basic age, gender, and pathology, the majority of papers poorly described ethnic background, height, or weight values. Because it was unclear what the basic characteristics and demographics were of these samples, it would be difficult to generalize the findings of these studies to a specific patient group. In general, the evidence base presented with studies recruiting small samples, without the inclusion of a power calculation to justify sample size. The methods of assessing various outcome measures were described in all but nine studies reviewed, whereas the method of dissection was not clearly defined in 13 papers. When used, the radiological evaluation of the knee was defined in two of the three papers reviewed.

Study observers were clearly defined in Holt et al. (2008) and Peeler and Anderson's (2007) papers, whereas the observer's reliability was evaluated in four papers. The observers were only blinded to specimen or subject pathological status in two papers.

On appraisal of the literature, few authors used inferential statistics to analyze their data. Inferential statistics were only used in nine papers, while no paper assessed the precision of their findings with confidence intervals. Descriptive statistics, such as means and standard deviation values to indicate variance, were present in 12 studies.

Findings were appropriately interpreted in the majority of studies reviewed. The clinical relevance of the papers assessed was clearly made in all, but three studies reviewed. Finally, the CASP tool highlighted that because the majority of papers poorly described their subject or specimen's basic charac-

teristic, the findings of these papers could not be generalized to a clinical population.

DISCUSSION

The findings of this review suggest that there is insufficient good quality evidence to suggest that the VM is composed of two separate components, the proximal VML and the distal VMO in healthy or pathological patellofemoral joints. Although a difference in fiber alignment was seen between proximal and distal muscle portions, it remains unclear whether the distal VM is supplied by a separate nerve supply from the femoral nerve. Furthermore, the previously reported existence of a fascial plane to further distinguish between these two muscles seems to have been the exception to the rule, being evident in 24% of the asymptomatic cases and 19% of the pathological patellofemoral joint cases reviewed in this systemic review.

The findings of this study should be considered with some caution because they presented with a plethora of methodological and presentational limitations. These included the limited description of the samples including not specifying specimen gender, pathology, ethnic background, or height, and the poor details of how each measurement was made and by whom in respect to training and experience in dissection and anatomical measurement. Therefore, measurement error may have significantly affected the findings of this review. Because assessment methods were unclear, it would be difficult to replicate and scrutinize the data collection methods. This factor may have considerably reduced the value of these studies. The small number of specimens and subjects recruited, and the limited population characteristics mean that it is difficult to generalize these results to clinical practice. Finally, the statistical appraisal of the majority of the papers reviewed was poor. Further study should address this limitation, because rigor and appropriate statistical analysis would enable the reader to place greater confidence on study findings.

As acknowledged, the literature poorly described and analyzed important demographic characteristics. Consequently, it was only possible to attempt to determine whether gender had an influence on the findings of VM fiber orientation, innervation, or the presence of a fibrofascial plane. This was an important factor given the predominance of female subjects, which present with patellofemoral dysfunctions such as anterior knee pain (Csintalan et al., 2002; Dugan, 2005). This review suggested that gender may not be associated with morphological difference of the VM. However, because the evidence base was severely limited in size and in identifying both specimen characteristics and data collection methods, such a conclusion cannot be confidently stated. It is recommended that future studies clearly present the demographic data on gender, pathology, ethnic background, and height, for example, to assess whether these factors have an impact on the structural anatomy of the VM and the etiological of patellofemoral dysfunction. This would then provide

greater external validity to the evidence base and improve its value to clinicians.

Five studies evaluated the morphology of the VM with pathological groups: patellofemoral degenerative changes (581 knees) and patellar instability (10 knees). These papers reported similar findings with respect to VM fiber orientation and the presence of a fibrofascial plane when compared with nonpathological, asymptomatic specimens and subjects. However, with few studies investigating pathological cadavers or subjects, it was not possible to assess whether these anatomical differences related to patellofemoral joint etiology.

Nonetheless, muscle fiber orientation and line of force have been previously hypothesized to affect VMO onset timing and synchronicity in relation to surrounding muscles, principally the VL (Ahmed et al., 1983; Fulkerson, 1997). It has been suggested that this may be a causative factor for anterior knee pain (Terry, 1989; Fulkerson, 1997; Grelsamer and Klein, 1998; Grelsamer and McConnell, 1998; Hubbard et al., 1998; Raimondo et al., 1998). This is based on the hypothesis that the VMO limits lateral translation continuously throughout the entire range of movement (Amis and Farahmand, 1996; Herrington, 1998). As the VMO contracts, the patella is forced into a more centralized position in the trochlear (Sakai et al., 2000). Accordingly, a weak or atrophied VMO permits the patella to be pulled more laterally as the vastus lateralis (VL) and lateral retinaculum overcome the resistive medial force of the insufficient VMO and medial retinacular tissues (Goh et al., 1995; Farahmand et al., 2004; Senavongse and Amis, 2005). The clinical assessment and rehabilitation protocols for patellofemoral joint dysfunction are commonly based on this assumption that there is a relationship between strength and onset timing to angle of orientation of the distal fibers of the VMO to impact on patellar stability (Peeler et al., 2005; Blazeovich et al., 2006).

Only Bose et al. (1980) provided evidence to support the suggestion that the morphology of the VM may be pathological. This study was the only review, which assessed patellar instability cases, reporting that in some instances fiber orientation was transverse, as opposed to oblique. This is exceptional when compared with nonpathological and degenerative patellofemoral joint cases. However, Bose et al. (1980) did not present their data quantitatively, giving no indication on actual fiber orientation in degrees, or the proportion of their 10 cases to which this is related. Further study is required to assess whether this finding was an exception, and to determine the degree of fiber orientation of the VMO and VML in patients with patellar instability.

Hypothetically, the VM's innervation may also be an etiological factor to patellofemoral dysfunction. Patients who present with a single branch of the femoral nerve may have poorer motor synchronicity and control when compared with those with two branches. This is supported by the findings by Galtier et al. (1995), the only study identified which assessed the difference in VM's innervation with pathological specimens. They reported a significant correlation with location of lesion and innervation, concluding that specimens with one nerve branch presented with lat-

eral fact lesions, whereas the location of lesion was more dispersed in those with two branches. Therefore, a single innervation may be an anatomical factor in the failure in patellar alignment to cause lateral facet lesions (Galtier et al., 1995). However, this review assessed specimens that had no history of knee complaint during their life, and therefore, further study may be indicated to assess whether this finding can be generalized to symptomatic populations, rather than a population with observable degenerative changes, which were asymptomatic. Until further study is undertaken assessing the relationship between fiber orientation, innervation, and pathology, such assumptions should be interpreted with caution. This may then inform surgeons and physiotherapists as to whether altering the fiber orientation surgically, or addressing onset timing with a muscle reeducation program with anterior knee pain or patellar instability cohorts, are indicated.

Nozic et al. (1997) suggested that the presence of a fascial plane dividing the VMO and the VML would give a structural basis for the division of the VM into two discrete parts. This review concluded that given the present insufficient evidence, it is not possible to state whether the VM is composed of two separate components and that the presence of a fascial plane should be regarded as an exception to the rule. Ono et al. (2005) suggested that the areolar fascial plane is not the definite criterion for division of the two portions of the VM. This questions how we distinguish distinct muscles and whether the existence of a separate fibro-fascial plane is paramount. We suggest that to be regarded as a separate muscle, the VMO and VML should repeatedly exhibit a number of individual morphological characteristics and have an independent contractile role or action to the other muscle, allowing it to be both structurally and functionally independent.

The age of cadavers used to assess for the presence of a fibrofascial plane is an important variable as most older specimens do not exhibit an intermuscular septum and is only exhibited in younger specimens (Karamanidis and Arampatzis, 2005; Kubo et al., 2007). On further scrutiny, the age of the cadavers was only documented in 5 of the 11 studies assessed. This ranged from 16 to 100 years, with a mean age of 73.9 years. Accordingly, the age of the specimens assessed may have been the reason why only a small proportion of cases exhibited a VM fibrofascial plane. If younger specimens were analyzed, these findings may have been different. Because of the considerable morphological changes that occur with age, it is very difficult to make generalizations from these results. Furthermore, because the studies which did provide data on the age of their cases, they did not present their findings based on subject age, and therefore, it was not possible to determine how important this factor was in this review. In future, age and other demographics should be controlled to limit the potential for such factors to act as confounding variance.

Although this review suggested that morphological factors may define whether the VM should be considered as a single anatomical structure or as two independent muscles, we suggest that further assessment of the role and function of the VM should be evaluated. Further study should be undertaken using

EMG analysis to assess the credibility of such a statement before we regard the extensor mechanism as a five muscle complex.

Finally, the studies reviewed poorly detailed subject characteristics, particularly ethnic group. This may be important because people from an Asian ethnic background have relatively smaller patella than Caucasians (Ono et al., 2005; Pagnano et al., 2006; Watanabe et al., 2008). Both studies suggest that further study may be warranted to determine whether inferences on VM morphology can be generalized to other ethnic groups and to assess whether these relate to any differences in musculoskeletal disorder prevalence and management.

CONCLUSIONS

The VM morphology has been largely based on Lieb and Perry's (1968) seminal cadaver work. This systematic review supports Lieb and Perry's (1968) initial findings concluding that a substantial alteration in fibers alignment can be seen between proximal and distal muscle portions. However, there was little evidence to support their observation of the frequent existence of a fascial plane to further distinguish between these two muscles, while there was ~55% mix of subjects reviewed who presented with either one or two nerve branches to the VM. Therefore, there is presently insufficient evidence to state whether the VM is composed of two separate components. Future study is now suggested to correlate these findings to pathological groups, such as patellar instability and anterior knee pain cohorts, to determine the pathophysiological relevance of these anatomical factors to patient's management.

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