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ORIGINAL ARTICLE

Anatomical Association between Articularis Genus and Vastus Medialis Oblique: A Cadaveric Investigation

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Abstract

Objectives: The articularis genus (AG) muscle is thought to elevate the suprapatellar bursa during knee extension. The AG and the vastus medialis oblique (VMO) both attach to the vastus intermedius aponeurosis, and there are also interconnections between the VMO and the AG. The AG and the VMO are both implicated in anterior knee pain. The aim of the study was to investigate if an anatomical association could be shown between the AG and the VMO.

Methods: Twenty-nine lower limbs were dissected to show the muscles of the anterior thigh. The maximum VMO pennation angle and the VMO insertion ratio on the medial border of the patella were measured. The AG area was determined by measuring the length and maximum width of each individual muscle slip.

Results: The mean area of the AG was 2554.67 mm². The mean VMO angle was 56.6°, whilst the mean insertion ratio was 48.93%. The association between area and each of the covariates was not statistically significant (VMO angle: P=0.921; insertion ratio: P=0.822). The mean area for the left thigh was greater than that for the right (2876.12 versus 2233.22; P=0.049).

Conclusion: The articularis genus does not appear to have an anatomical association with the vastus medialis oblique. The dimensions of the superficial layer of the AG were not influenced by sex or age. However, the AG area was greater on the left limb than the right.

Key Words: *Patellofemoral pain; Articularis genus; Vastus medialis oblique; Patellar tracking; Suprapatellar bursa*

Introduction

The quadriceps femoris (QF) muscle group, in the anterior compartment of the thigh, consists of the rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM), and vastus intermedius (VI) muscles. The articularis genus (AG) lies deep to the QF group, posterior to the VI [1-3], and has been described both as a separate muscle [1,2,4], and as an extension of the VI [3,5].

The AG inserts into the knee joint capsule and the proximal edge of the suprapatellar bursa [6-8]. Its proposed function is to elevate the suprapatellar bursa during knee extension, thereby preventing the bursa becoming compressed between the femur and patella [3,6].

The AG is reported to be present in 80%-100% of the population [1,2,6]. It is a small, flat muscle lying on the distal third of the anterior femur [1,2]. The mean length of the AG ranges from 6.17 cm to 13.9 cm [4,7]. However, there are challenges in definitively identifying the AG, due to the lack of a clear distinction between the proximal AG and the VI.

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The anatomy of the AG appears to be variable. It has been variously reported that that the muscle has one layer and 1 or 2 muscle slips [2], 2-5 slips [7], 4-10 slips in superficial, intermediate and deep layers arising from the anterior femur [7], at least 10 slips in superficial and deep layers, with the superficial layer arising from the VI, and the deep layer arising from the anterior femur [3]. Grob et al. [5] found that in 60% of cadavers the intermediate layer originated from the VI, the remaining 40% from the femur.

Empirical evidence of the AG's function appears to be limited to one study involving 3 patients with lower limb amputations. When their femoral nerves were stimulated, the suprapatellar bursa was elevated by the AG [2]. The small size of the AG has, however, created doubts about its capacity to perform this function [5,7]. Articularis genus insufficiency may lead to anterior knee pain [7], and patients with AG atrophy were found to have reduced knee mobility and knee pain [9].

There is some evidence that the AG, VI and the VM work together as a functional unit. All three muscles are innervated by the same 'medial deep division of the femoral nerve' [5], and it has been found that they also undergo atrophic or hypertrophic changes proportionally [4,6]. Furthermore, they all have direct anatomical connections, and deep fibres of the VM insert into the superficial bundle of the AG at the joint capsule [5].

The VM is described as consisting of two parts, vastus medialis oblique (VMO) and vastus medialis longus (VML), depending on the angulation of its fibres [10,11]. The more distal oblique fibres insert into the medial edge of the patella, helping to maintain patella tracking [12], and VMO insufficiency is associated with patella maltracking and anterior knee pain [13-15]. There is variation in the maximum fibre angle, and the insertion level (the level at which the distal VMO inserts into the medial border of the patella) [16], with athletic individuals generally having a greater fibre angle and more distal insertion level than sedentary individuals [17].

Aims

Anatomical features of both the AG and the VMO have been implicated in anterior knee pain. The interconnections between AG and VMO suggest that there may an anatomical, and possibly, function association between the two muscles. In this study, the aim was to explore if a functional association was manifested as an anatomical association.

The objectives of the study were:

- To measure the area of the superficial layer of the AG, the VMO pennation angle, and the VMO insertion ratio (the insertion level expressed as a percentage of patellar length)
- To determine if an anatomical relationship exists between the AG and the VMO
- To explore the effect of sex, side, and age on these parameters.

Materials and Methods

Twenty-nine lower limbs (13 paired and 3 unpaired) were used in this study, from cadavers that had been donated for medical education and research under the Human Tissue Act (2004). Seven pairs were from female cadavers, six from males. The unpaired limbs were two males and one female. The mean age (± SD) of the cadavers was 84.9 (± 11.1), range 50-98 years. Medical history was not available, but limbs showing signs of pathology or previous surgery were excluded.

The limbs were placed supine, with the knee extended. A midline incision was made, and the skin reflected to expose the quadriceps muscles. The VMO fibre angle was measured with respect to the femoral axis. The femoral axis was determined from the middle of the femoral shaft to the apex of the patella, using string between two pins. The fibre angle was determined using a clear protractor, which was accurate to 1 degree. To reduce error, all measurements were taken by the same observer from the same position, and all measurements were repeated three times.

The VMO insertion ratio was calculated by dividing the insertion level of the VMO by the length of the patella, expressed as a percentage. The patellar length was measured from the base to the apex. The VMO insertion level was measured from the patellar base to the most distal fibres of the VMO. Measurements were taken using digital callipers, accurate to 0.01 mm (Figure 1).

The QF muscles were identified, dissected free of the femur, and then reflected inferiorly past the patella, leaving the AG attached to the anterior femur (Figure 2). Careful blunt dissection, using curved scissors, was used to separate the fibres of the AG from the QF muscles as they were reflected.

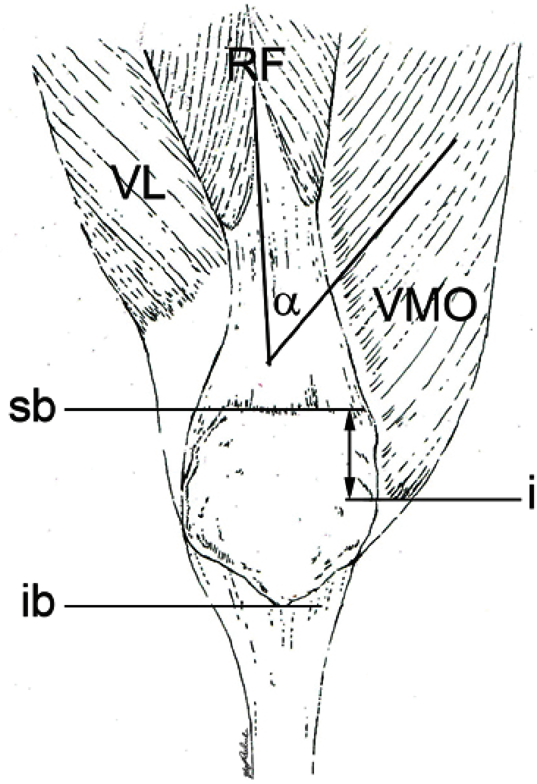

Figure 1) *Drawing showing the measurements of the VMO. sb, superior border of patella; ib, inferior border; il, insertion level; α, VMO fibre angle; RF, rectus femoris; VL, vastus lateralis; VMO, vastus medialis oblique.*

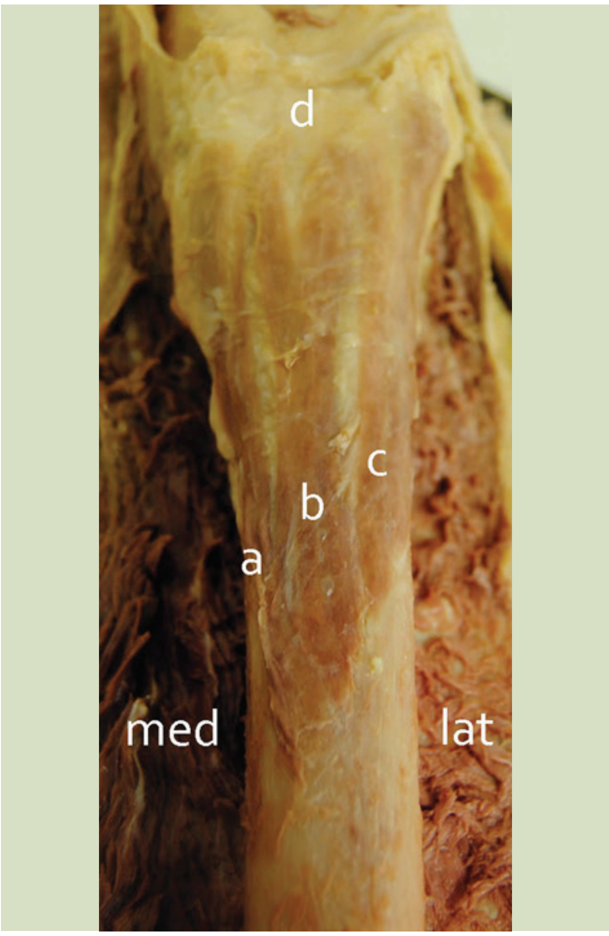

Figure 2) *The superficial layer of the articularis genus. Showing a, anterolateral; b, central; and c, anteromedial slips; d, suprapatellar bursa.*

The number of AG muscle slips was noted. A muscle slip was defined as fascicles that have a 'common origin, insertion, and orientation' [7]. Digital callipers were used to measure the length of each slip and its maximum width.

Statistical Analysis

The cadavers were independent of each other, whilst the left and right limbs within cadavers were not. Therefore, a generalised linear mixed model with repeated measures, with a linear link function was used to investigate the association between the area of AG and the pennation angle and insertion ratio of the VMO. The pennation angle and insertion ratio were entered as covariates. The factors of sex (male versus female), categorised age (less than 85 years versus greater than or equal to 85 years) were included as between-subject variables, and side (left versus right) as a within-subject variable.

Traditional hypothesis testing with a critical level of significance of 0.05 was used. All results were adjusted through the multivariate model. The presented means are least squares means, having been adjusted for a potential imbalanced design, and accounting for the hierarchical structure of the design. The categories of the fixed factors were compared in mean area using pairwise comparisons. All analyses were performed using SPSS Version 26.

Results

The AG was found in 100% of the specimens. The mean AG area was 2519 mm^2. The mean number of slips was 2.83. It was found that 82.8% of the specimens had 3 slips, and 17.2% had 2 slips. The slips were designated as central, anterolateral, and anteromedial, based on their position on the femur. The central slip had the greatest mean length and width (77.9 mm and 15.5 mm respectively) and was found in 100% of the specimens. The anterolateral slip was found in 93.1% and the anteromedial slip was found in 89.7% of the specimens. The anteromedial slip had a greater mean length than the anterolateral slip (69.5 mm versus 68.4 mm). However, the anterolateral slip had a greater mean width than the anteromedial slip (10.2 mm versus 9.02 mm) (Table 1).

All the paired limbs had the same number of slips on both sides, except for one cadaver, which had 3 slips on the left and 2 on the right (the anteromedial slip was lacking).

TABLE 1
Summary of articularis genus (AG) muscle slip measurements

	No. of slips	Central slip length (mm)	Central slip width (mm)	Antero-lateral slip length (mm)	Antero-lateral slip width (mm)	Antero-medial slip length (mm)	Antero-medial slip width (mm)	AG area (mm^2)
Mean ± SD	2.83 ± 0.38	77. 9 ± 17.0	15.5 ± 6.98	68.4 ± 16.4	10.2 ± 4.17	69.5 ± 17.2	9.02 ± 6.00	2519 ± 1041
Range	3-Feb	49.81-115.25	2.55-30.73	33.49-98.30	5.56-23.08	29.63-101.31	4.03-27.55	1081-5826

The mean VMO angle was 56.6°. The mean patellar length was 53.5 mm, and the mean VMO insertion level was 26.0 mm. The mean insertion ratio of 48.93%. All specimens had medial attachment to the patella, ranging from 15.4% to 90.4% (Table 2).

Results from the generalised linear mixed model

The overall mean AG area across all lower limbs was 2554.67 mm^2 (95% CI: 2021.59-3087.74 mm^2). The results of the generalised linear mixed model are shown in Table 3. The association between area and each of the covariates was not statistically significant (VMO angle: P=0.921; insertion ratio: P=0.822).

Results from the pairwise comparisons

The AG area was statistically significant for side. The mean area on the left limb was greater than that on the right (2876.12 versus 2233.22, P=0.049). However, there was no statistically significant difference between the sexes (P=0.121), or between categorised age groups (P=0.779) (Table 4). When undertaking the pairwise comparisons, the mean values for the covariates were fixed at 56.62° for VMO angle and 48.93% for insertion ratio.

TABLE 2
Summary of VMO measurements

	VMO insertion (mm)	Patella length (mm)	VMO insertion ratio (%)	VMO angle (°)
Mean ± SD	26.0 ± 8.97	53.5 ± 6.78	48.93 ± 17.38	56.62 ± 6.38
Range	8.16-48.77	37.82-69.10	15.39-90.38	42-67

TABLE 3
Results from the generalised linear mixed model showing the coefficient (SE), 95% CI and P- value for the VMO angle and insertion ratio

Factor	Coefficient (SE)	95% CI	P-value
VMO angle	2.36 (23.556)	(-46.43, 51.16)	P=0.921
Insertion ratio	3.49 (14.51)	(-37.27, 44.25)	P=0.822

For age comparisons, there were 18 limbs from cadavers with age >85 (range 87-98 years), and 11 with age ≤ 85 (range 50-81 years). The specimen from the donor aged 50, an unpaired left lower limb, was an outlier (the next youngest donor was 72 years old). The results from this limb were noticeably different from the mean: AG area 2328 mm^2 (mean for left limbs 2876 mm^2), VMO insertion ratio 37.18% (mean 48.93%), VMO angle 61° (mean 56.62°).

TABLE 4
Results from the pairwise comparison showing the mean, mean difference and P-values for left/right leg, female/male, and LT (less than) 85/GE (greater than or equal to) 85 years age groups

Factor	Mean (SE)	Mean Difference (95% CI)	*P*-value
Within-subject			
Leg			
Right	2233.22 (249.064)		*P*=0.049
Left	2876.12 (290.555)	642.90 (2.739, 1283.061)	
Between-subject			
Sex			
Female	2238.55 (241.177)		*P*=0.121
Male	2870.74 (332.273)	632. 24 (-198.77- 1463.25)	
Categorised Age (years)			
LT 85	2611.12 (354.922)	112.92 (-770.41, 996.25)	*P*=0.779
GE 85	2498.21 (221.62)		

Discussion

AG measurements in relation to side, age, and sex

The mean length of the central, anterolateral, and anteromedial slips was 7.79 cm, 6.84 cm, and 6.95 cm, respectively. These values are similar to previous cadaveric studies [1,2,4]. Woodley et al., [7] found a greater mean length of 13.9 cm. This may be due to the different dissection techniques employed. Woodley et al. [7] performed midline incisions on the VI, reflecting the muscle medially and laterally. However, as Grob et al. [5] found, there is no proximal separation between the VI and the AG, which may have led to Woodley et al. including fibres of the VI as part of the AG.

The mean width of the central, anterolateral and the anteromedial slips was 1.55 cm, 1.02 cm, and 0.902 cm, respectively, (range 0.255 cm-3.08 cm), giving a combined width of 3.47 cm. There is limited literature regarding the width of the AG, however, Reider et al. [18] reported a combined width of 1.5-3 cm.

The mean AG area was greater on the left than on the right (P=0.049). Assuming a functional relationship between size and effectiveness, this suggests that the right knee would be more susceptible to PFP. This finding is surprising, since 80%-90% of the population are right-leg dominant [19]. The right leg, experiencing greater loading than the left, and, therefore, increased neurostimulation, would be expected to have the larger AG [9].

In one individual, the area of the left AG was nearly 2.5 times greater than the right. The right limb lacked an anteromedial slip, which may explain the disparity. However, there were also differences in the VMO parameters between the two specimens. The insertion ratio and pennation angle on the left limb (67° and 50.66%, respectively) were noticeably greater than that on the right (43° and 41.46%). While it is not possible to draw conclusions from a single example, it does suggest that an underdevelopment of the anteromedial might be correlated with an underdevelopment of the VMO.

There was no statistically significant difference in AG area between the categorised age groups >85 years, and ≤ 85 (P=0.779). The mean age was 84.9 years, and activity levels likely to be low in both age groups, which may explain the similarities in the two groups.

One left lower limb (the right limb was not available) from a fifty-year-old individual was an outlier. The age range of the others was 72-98 years. Interestingly, the AG area was below the left limb mean (2328 mm^2 versus 2876 mm^2). The VMO insertion ratio was also below the mean (37.18% versus 48.93%). However, its VMO angle was greater than the mean (61° versus 56.62°). The significance of these findings in not clear.

There was no statistically significant difference in AG area between the sexes (P=0.121). It might be expected that, as females have a higher prevalence for anterior knee pain [20] they may have a smaller

AG area. However, PFP is more prevalent in young females, which were not represented in this study.

VMO measurements

The mean maximum VMO angle was 56.6 (± 6.38°), which falls within the range reported by other cadaveric studies [10,21-23]. Hubbard et al. [22] found a broader range of 28° to 70°, though this may be due to their larger sample size of 374. The mean insertion ratio was 49.0% (range 15.4%-90.4%). This is below the ratio reported by other studies [16,21], which may be due to differences in the age of the study populations.

Association between the articularis genus and the vastus medialis oblique

Given that articularis genus insufficiency is associated with anterior knee pain [7,9], and that AG, VI and VM have been shown to form a functional unit [4-6], and furthermore, that there are direct anatomical connections between the AG and QF muscles [5], it is not unreasonable to suspect that there may be a functional, as well as anatomical association between them.

However, in this study, no association was found between the AG area and the VMO insertion ratio (P=0.822), or pennation angle (P=0.921), which suggests that these muscles do not have an anatomical and functional association. It is widely believed that the VMO has a role in preventing patellar maltracking and that VMO insufficiency is a contributing factor to PFP, although some studies dispute this [24-26]. The aetiology of patellofemoral pain is reported to be multifactorial, with abnormalities in hip abductor muscles and hindfoot posture also implicated [27]. Jan et al. [14] found that a quarter of symptomatic patients had a VMO insertion ratio greater than 60%, while less than half of patients with patellofemoral pain were found to have isolated lateral patellar displacement [13], suggesting that, in those cases, the muscle was not deficient, and factors other than the architecture of the VMO are involved in the aetiology of PFP.

In this study, we chose to examine the VMO, but connections with the VI and the VL may also have a critical role. Furthermore, the fascicles within the AG muscle slips may have a greater anatomical and functional significance. Woodley et al. [7] found that the greatest number were found in the central slip, and it may be that measuring fascicle lengths would have given a more accurate representation of function, as fascicle length is directly proportional to maximum force of muscular contraction [28].

The AG consists of superficial, intermediate, and deep layers, though the anatomy of the middle and deep layers is very variable, with up to six slips in the intermediate layer, and two to four slips in the deep layer [3,7]. This variability may have functional and clinical significance. In particular, the anteromedial slip of the deep layer was found to have greater length and width than the anterolateral slip [5], and may help prevent lateral tracking of the patellar, in conjunction with the VMO. Underdevelopment of this bundle could be implicated in anterior knee pain.

Limitations

This study was carried out on formalin-fixed lower limbs, from donors who were all (except for one) over 70 years of age, while PFP is a condition that is common in younger individuals. Age-related muscular atrophy is common within the elderly [29], therefore, the measurements are not representative of the wider population. Furthermore, fixation of cadaveric tissue can lead to shrinkage [30]. The narrow age range means that analysis of age-related trends was limited.

Conclusion

The articularis genus does not appear to have an anatomical association with the vastus medialis oblique. The dimensions of the superficial layer of the AG were not influenced by sex or age. However, the AG area was greater on the left limb than the right.

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