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Why adductor magnus muscle is large: The function based on muscle morphology in cadavers

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The aim of this study was to examine anatomical properties of the adductor magnus through a detailed classification, and to hypothesize its function and size to gather enough information about morphology. Ten cadaveric specimens of the adductor magnus were used. The muscle was separated into four portios (AM1–AM4) based on the courses of the corresponding perforating arteries, and its volume, muscle length, muscle fiber length and physiological cross-sectional area were assessed. The architectural characteristics of these four portions of the adductor magnus were then classified with the aid of principal component analysis. The results led us into demarcating the most proximal part of the adductor magnus (AM1) from the remaining parts (AM2, AM3, and AM4). Classification of the adductor magnus in terms of architectural characteristics differed from the more traditional anatomical distinction. The AM2, AM3, and AM4, having longer muscle fiber lengths than the AM1, appear to be designed as displacers for moving the thigh through a large range of motion. The AM1 appears instead to be oriented principally toward stabilizing the hip joint. The large mass of the adductor magnus should thus be regarded as a complex of functionally differentiable muscle portions.

The adductor magnus muscle is a member of the adductor group of the lower extremity or hip adductors, along with the obturator externus, pectineus, adductor longus, adductor brevis, and gracilis. It takes up 27% of the mass of the thigh musculature (Ishida, 1972). The adductor magnus is the largest of the hip adductors and the third largest among all of the muscles in the lower limb, is only smaller than the quadriceps femoris and the gluteus maximus (Ishida, 1972; Ito et al., 2003). But what does this muscle do? In spite of electromyographic work dating as far back as the 1960s, the function of the adductor magnus remains difficult to explain. Basmajian (1962) expressed surprise that so little information has been obtained concerning what must be an important muscle.

Rasch (1989) pointed out the contradiction of attributing the mere function of hip adduction to such a large muscle that would surely play a critical role in gait, indicated that the hip adductors had some roles as hip rotator and flexor. Perry and Burnfield (2010) examined muscle activity during gait, showing that the adductor magnus activity was increased at the initial contact because of absorbing some of the shock of floor contact while preserving progression and postural stability by optimally positioning the limb. Interestingly, the active phase of the adductor magnus during gait was clearly different from that of the adductor longus.

In competitive sports, the hip adductors are known to have an important role, made apparent by their being vulnerable to injury (Speer et al., 1993; Nicholas & Tyler, 2002; Armfield et al., 2006). Among professional soccer athletes, the most frequently injured muscle group is the quadriceps femoris (32%), followed by the hamstrings (28%) and the hip adductors (19%) (Volpi et al., 2004). Groin pain, which is typically associated with the hip adductors, occurs relatively frequently in sports activities involving rapid change in direction of hip motion (Nicholas & Tyler, 2002; Robinson et al., 2004), such as soccer (13%) (Hawkins et al., 2001), ice hockey (10%) (Lorentzon et al., 1988), and the breaststroke in swimming (43%) (Grote, 2004). Among the hip adductors, the adductor longus is frequently reported as being injured (Speer et al., 1993; Armfield et al., 2006), but not the adductor magnus.

Such architectural characteristics as muscle fiber length and physiological cross-sectional area form a basis for understanding muscle function (Lieber & Fridén, 2000). As a fan-shaped structure, the adductor magnus may exhibit different function among its top, middle, and bottom portions, based on architectural differences. In addition, this muscle receives its double innervation from the tibial nerve portion of the sciatic nerve, and the posterior branch of the obturator nerve. Interesting as this information may be, a more detailed analysis may lead to a deeper understanding of how the adductor magnus functions.

First, our aim was to investigate anatomical properties such as the fan-shaped structure and innervation of the adductor magnus, and to classify it into parts. Second, was to hypothesize roles and size of the adductor magnus, to gather enough information about morphology, hopefully enabling us to understand why such a large muscle would receive relatively little attention in investigations of injury or atrophy.

Materials and methods

Specimens

Seven left and three right lower limbs were examined from 10 embalmed cadavers. Age at death was 75–91 years (average: 79 years). Specimens involving histories of neuromuscular disease, joint contracture, or marked muscular atrophy or extra muscle were specifically avoided. Each cadaver was given a number and the age, gender, and medical histories were recorded. Approval for this study was obtained from the Human Ethics Committee of Sapporo Medical University School of Medicine.

Gross dissection

After being dissected free, the adductor magnus was divided into four parts based on courses of the corresponding perforating arteries from the deep femoral artery. The first portion of the adductor magnus (AM1) was that part of the muscle proximal to the first perforating artery. When this portion is clearly distinguishable from other parts of the adductor magnus, it is referred to as the adductor minimus. The neighboring portion, AM2, was located in the region between the first and second perforating arteries. The third portion, AM3, lay distal to AM2 but proximal and lateral to the adductor hiatus. The remaining portion, AM4, was distal and medial to the adductor hiatus (Fig. 1).

Innervations of these four portions by the posterior branch of the obturator nerve and the tibial nerve portion of the sciatic nerve were visually confirmed. The posterior branch of the obturator nerve was identifiable from its relation to the adductor brevis, and the tibial nerve from following its course after it exited the sciatic nerve.

Measurements

Muscle length, muscle fiber length and physiological cross-sectional area of each portion of the adductor magnus were measured, and likewise in the pectineus, adductor longus, and adductor brevis (Fig. 2). The obturator externus was chosen not to be measured because its course and action appeared to clearly differ from the above adductors. Likewise the gracilis was excluded from the comparison, because it functioned differently as a biarthrodial muscle. The four portions of the adductor magnus and the three other muscles subject to measurement were stripped from their bony attachments with a scalpel. Surface connective tissue, blood vessels, and nerves were separated and removed from the muscle tissue prior to measurements.

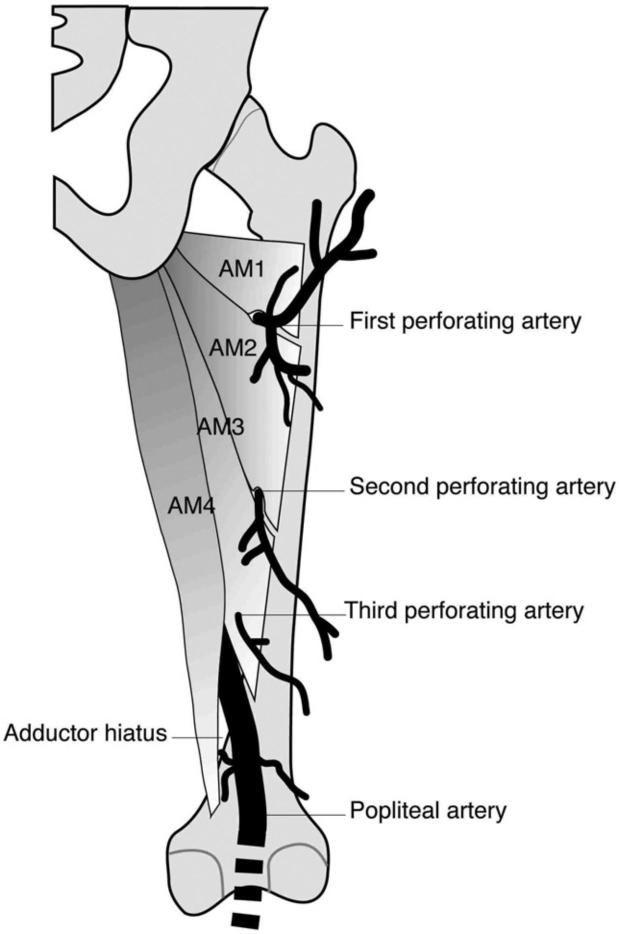

Fig. 1. Four portions of the adductor magnus (AM1-AM4) based on courses of the corresponding perforating arteries from the deep femoral artery.

Volume was determined by immersing the specimen into a graduated cylinder containing water and noting the resulting increase in water level. To measure muscle length and muscle fiber length, first the muscle was laid out from origin to insertion. Muscle length was determined as the length of everything including tendon and fascia, whereas muscle fiber length was length of the intermediate part comprising the muscle tissue proper (Fig. 2). A angle of pinnation of the measured muscles were approximately 0 degree, but that of the adductor longs about 6 degree (Wickiewicz et al., 1983). Thus, for physiological cross-sectional area, the muscle was sectioned perpendicular to the direction of the muscle fibers at the largest part of its belly, not necessarily in an arbitrary anatomical plane. The cross-section was photographed and the area of that cross-section subsequently measured with the aid of imaging analysis software (Image J, National Institutes of Health, Bethesda, Maryland, USA). The conventional way to determine physiological cross-sectional area is to divide volume by muscle fiber length (Fukunaga et al., 1992; Lieber, 2002), but in this study, the way should be avoided because our statistical analysis requires independent measured values, so we directly measured the cross-sectional area. One person (MT) performed all of the measurements. These actual measurements will be referred to in the next paragraph as *raw measurements*.

Multivariate analysis and other statistical procedures

To account for dimensional differences among the 10 specimens, length of the femur, defined as distance between the greater tro-

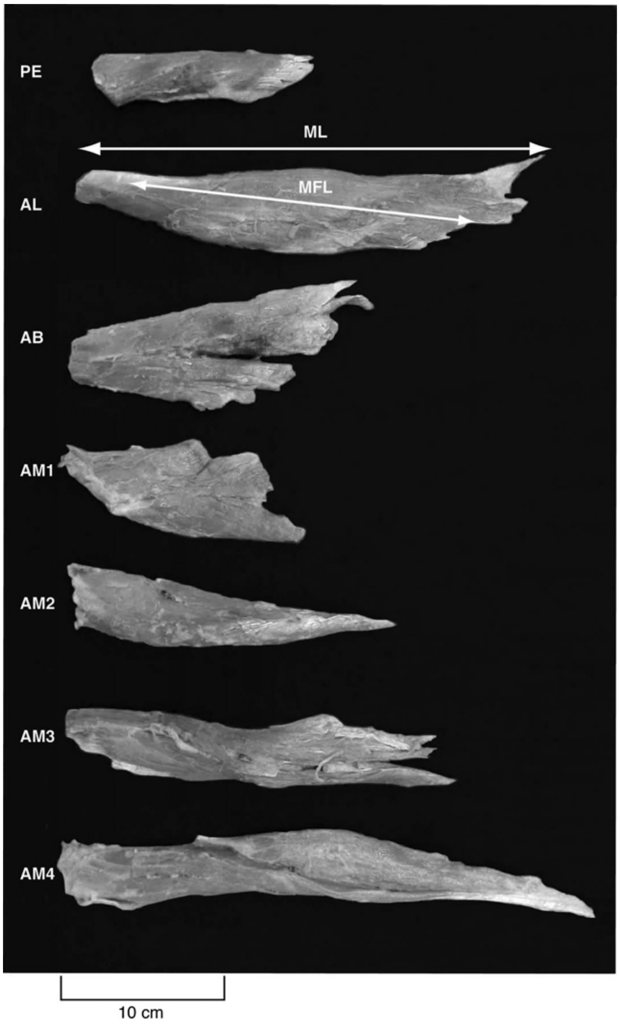

Fig. 2. Portions of the adductor magnus and the comparative adductor muscles. PE, pectineus; AL, adductor longus; AB, adductor brevis; AM1-AM4, adductor magnus; ML, muscle length; MFL, muscle fiber length.

chanter and lateral epicondyle, was used as a basis for normalization. A corrective factor was determined by dividing the mean of the ten specimens by the value of the particular specimen in question. The raw measurements were normalized by multiplication with the corrective factor.

For the adductor magnus (AM1–AM4), pectineus, adductor longus, and adductor brevis, normalized values of volume of muscle length, muscle fiber length, and physiological cross-sectional area were subjected to principal component analysis (Jacobs et al., 2009; Salaj & Markovic, 2011). Next, to ascertain whether pairings from the results of principal component analysis of the four portions (AM1–AM4) of the adductor magnus were appropriate, Scheffé linear contrasts were used for multiple comparisons (Fig. 3). These procedures were performed with the aid of Statistical Package for the Social Sciences for Windows, Ver. 19 (IBM, Armonk, New York, USA), with the level of significance set at 5%.

Results

Anatomical properties of the adductor Magnus

The adductor magnus was fan-shaped, narrow at its proximal origin, and wide at its insertion. This muscle was flanked ventrally by the adductor longus and adductor brevis, dorsally by the semitendinosus and semimembranosus, and medially by the gracilis. Whereas the AM4 was palpable just under the skin, the other three portions were more deeply located and not so accessible to direct palpation. The perimysium between the AM1 and AM2 was well developed and could easily be separated from the neighboring muscle tissue, but a fascial sheath common to the proximal parts of the AM2, AM3, and AM4 became more difficult to tease out. Determining the boundaries of the pectineus, adductor longus, and adductor brevis was much easier. The AM1 of the adductor magnus originated from the inferior ramus of the pubis and inserted along the medial side of the gluteal line down to the superior part of the linea aspera along its medial aspect. The AM2 had for its origin an area stretching from the inferior ramus of the pubis to the inferior ramus of the ischium, and for its insertion, the medial lip along the central extent of the linea aspera. The AM3 had its origin from the inferior ramus to the tuberosity of the ischium and its insertion on the medial lip along the inferior extent of the linea aspera. Finally, the AM4 originated from the medial aspect of the ischial tuberosity and inserted on the adductor tubercle. The AM1 and AM2 received the posterior branch of the obturator nerve, and AM3 both the posterior branch of the obturator nerve and the tibial nerve portion of the sciatic nerve. The AM4 was innervated by the tibial nerve portion of the sciatic nerve (Fig. 4).

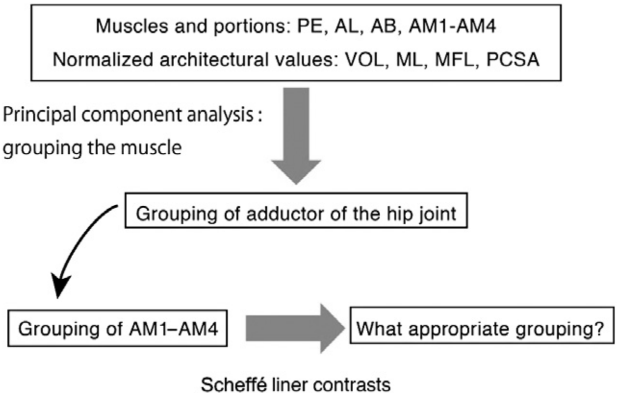

Fig. 3. Multivariate analysis and statistical procedures flow. PE, pectineus; AL, adductor longus; AB, adductor brevis; AM, adductor magnus; ML, muscle length; MFL, muscle fiber length; VOL, volume; ML, muscle length; MFL, muscle fiber length; PCSA, physiological cross-sectional area.

Comparative architectural properties among muscles measured

Refer to Table 1 for normalized values of individual muscles and portions. The total volume of the adductor magnus, pectineus, adductor longus, and adductor brevis was 360.1 ± 72.9 cm^3 (mean ± standard deviation),

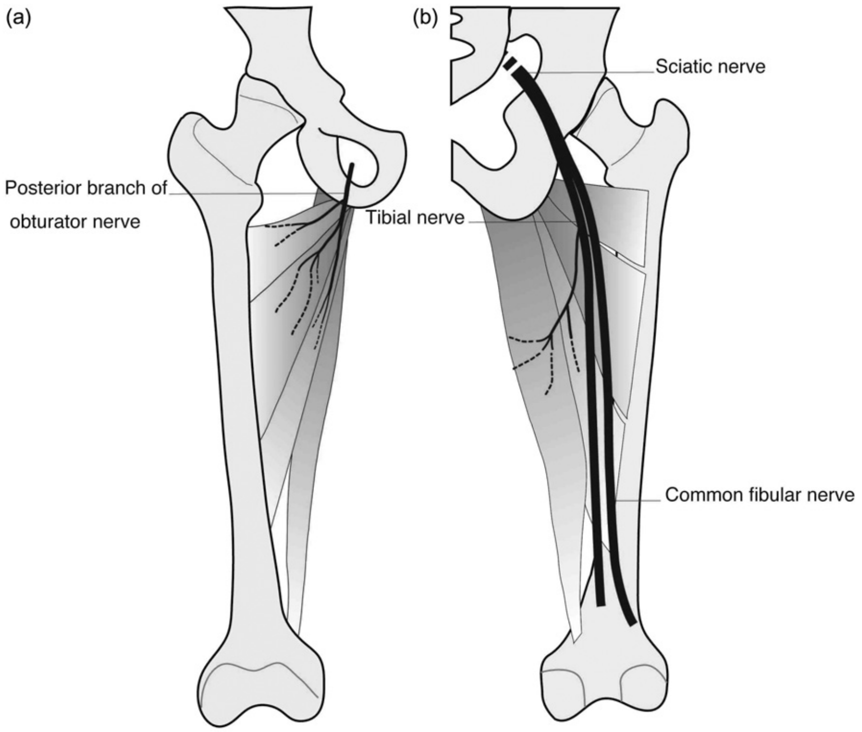

Fig. 4. Innervations of the four portions adductor magnus by the posterior branch of the obturator nerve and the tibial nerve portion of the sciatic nerve. (a), anterior view; (b), posterior view.

Table 1. Architectural properties about the hip adductors ($n = 10$)

	PE	AL	AB	AM1	AM2	AM3	AM4
VOL (cm^3)	21.2	62.8	47.3	28.7	53.9	72.3	73.9
	(6.8)	(12.4)	(12.3)	(8.2)	(15.0)	(21.2)	(22.3)
%VOL (%)	6.0	17.9	13.1	7.9	14.9	19.9	20.2
	(2.2)	(3.8)	(2.1)	(1.2)	(3.1)	(3.1)	(2.9)
ML (cm)	12.4	23.6	17.2	12.4	20.8	23.4	30.8
	(1.3)	(1.8)	(1.9)	(1.8)	(3.0)	(1.9)	(2.1)
MFL (cm)	10.1	13.9	11.7	8.4	11.2	14.6	16.6
	(1.6)	(1.9)	(1.1)	(1.0)	(1.4)	(1.4)	(1.3)
PCSA (cm^2)	2.3	5.8	5.2	3.6	5.8	6.0	5.8
	(0.5)	(1.4)	(1.2)	(1.2)	(1.4)	(2.9)	(2.3)

Average (standard deviation).
Architectural values normalized by length of the femur.
VOL, volume; ML, muscle length; MFL, muscle fiber length; PCSA, physiological cross-sectional area; PE, pectineus; AL, adductor longus; AB, adductor brevis; AM, adductor magnus; ML, muscle length; MFL, muscle fiber length.

Table 2. Results of principal component analysis on the architecture

Item	Coefficient of principal components	
	First	Second
VOL	0.998	0.054
ML	0.959	–0.238
MFL	0.934	–0.327
PCSA	0.801	0.598
Eigenvalue	3.429	0.524
% variance	85.7	13.1

Principal component first contains over 80% of the total variance in the data.
VOL, volume; ML, muscle length; MFL, muscle fiber length; PCSA, physiological cross-sectional area.

with the adductor magnus accounting for 63.0% ± 6.0% of that volume. The AM3 and AM4 were relative large, each consisting of some 30% of the volume of the adductor magnus, whereas the AM1 provided only about 13%. Even with normalization, volume and physiological cross-sectional area exhibited notable variation among the specimens.

To search for distinguishing characteristics among the four portions of the adductor magnus, as well as the pectineus, adductor longus, and adductor brevis, a principal component analysis was performed based on volume, muscle length, muscle fiber length and on the physiological cross-sectional area. Only the first principal component had an eigenvalue exceeding unity, reaching 3.43 and yielding a contribution of 85.7% (Table 2). Among the muscles and portions measured, scores of the first principal component were negative for AM1, the pectineus, and the adductor brevis, and positive for the remaining portions of the adductor magnus as well as for the adductor longus (Table 3), suggesting a division of the muscles and portions studied into two groups. To further establish the appropriateness of grouping the components of the adductor magnus in this way, the values of these two groups were compared by Scheffé linear contrasts, which were significant ($P < 0.01$) for muscle length, muscle fiber length and volume, although not for physiological cross-sectional area. If, in contrast, the traditional distinction of dividing the adductor magnus into an adductor part (AM1, AM2, and AM3) and a hamstrings part (AM4) (Moore & Dalley, 2005) was made, Scheffé linear contrasts were significant for muscle length and muscle fiber length ($P < 0.01$), and volume ($P < 0.05$), but not physiological cross-sectional area (Table 4).

Discussion

With the aim of examining the adductor magnus in detail, the muscle was separated into four portions (AM1–AM4) based on the courses of the corresponding perforating arteries. The architectural characteristics of these four portions of the adductor magnus were then classified with the aid of principal component analysis (Jacobs et al., 2009; Salaj & Markovic, 2011). The results have mechanically led us into distinguishing between the most proximal part of the adductor magnus (AM1) and the remaining parts of the adductor magnus (AM2, AM3, and AM4). This distinction is based on volume, muscle length and muscle fiber length of each of these muscles or portions of muscle, although apparently not on physiological cross-sectional area. Does this division of adductors into two groups have a functionally interpretable meaning?

Table 3. Principal component scores of the hip adductors

Item	First component
PE	–1.38
AL	0.57
AB	–0.27
AM1	–1.17
AM2	0.11
AM3	0.97
AM4	1.17

PE, pectineus; AL, adductor longus; AB, adductor brevis; AM, adductor magnus.

Muscle fiber length is based on serial arrangement of sarcomeres of fixed length, so the longer the fiber length, the greater number of sarcomeres are assumed to be present, thereby increasing the possible magnitude of a joint movement (Wickiewicz et al., 1983; Lieber & Fridén, 2000). Physiological cross-sectional area, on the other hand, reflects the number and the size of muscle fibers running in parallel. The greater the physiological cross-sectional area of a muscle, the greater the potential for it to generate tension (Wickiewicz et al., 1983; Lieber & Fridén, 2000). This distinction has been illustrated for the hamstrings, in which the semimembranosus and long head of the biceps femoris have relatively short muscle fibers but large physiological cross-sectional areas, gearing them for production of high tension, whereas the semitendinosus and short head of the biceps femoris have longer fibers and are thus more oriented to full angular displacement at a joint (Woodley & Mercer, 2005). Insofar as moment arms of these muscles about the knee are all similar, such architectural distinctions can be important determinants of how the different muscles function. The AM2, AM3, and AM4 as defined in our study, having longer muscle fiber length than AM1, appear to be designed as displacers for moving through a large range of motion. During unilateral weight-bearing, the heavy trunk is liable to move in any direction on top of the ball-and-socket joint at the hip. Especially relevant is when the trunk is forwardly inclined, as the hip becomes markedly flexed and the longer portions of the adductor magnus (AM2–AM4) are positioned to strongly rotate the pelvis posteriorly, on the basis of enough moment arm about the hip joint (Dostal et al., 1986). As uniarthrodial structures, the AM2–AM4 portions can exert such strong torque regardless of whether the person is crouched or the leg is straightened. The AM1 portion, in contrast, is poorly designed for such heavy work with its smaller size and shorter moment arm and would be more suitable for stabilization of the hip.

Table 4. Compare of the groups by Scheffé linear contrasts

Item	Grouping of AM1-AM4					
	AM1 : AM2, AM3, AM4			AM1, AM2, AM3 : AM4		
	Mean†	95% CI	*F*-ratio	Mean†	95% CI	*F*-ratio
VOL (cm^3)	–38.0	(–56.8, –19.2)	11.64**	–22.2	(–41.1, –3.3)	3.97*
ML (cm)	–12.7	(–15.1, –10.3)	80.26**	–11.6	(–14.0, –9.2)	67.01**
MFL (cm)	–5.8	(–7.2, –4.4)	48.82**	–5.1	(–6.5, –3.7)	48.82**
PCSA (cm^2)	–2.2	(–4.4, –0.0)	2.78	–0.6	(–2.9, 1.6)	0.23

Mean† = estimated mean-value, *$P < 0.05$, **$P < 0.01$.

Grouping of AM1-AM4: architectural distinction (AM1 vs AM2, AM3, AM4), traditional distinction (AM1, AM2, AM3 versus AM4).

CI, confidence interval; VOL, volume; ML, muscle length; MFL, muscle fiber length; PCSA, physiological cross-sectional area; AM, adductor magnus.

Hip adductors tend to be strained in ice hockey and are typically associated with groin pain (Speer et al., 1993; Armfield et al., 2006). Professional road cyclists exhibit selective hypertrophy of the adductor magnus (Hug et al., 2006). Note that in these activities, the trunk is forwardly inclined and the thigh is moving through a wide range, suggesting an important role of the AM2–AM4 portions of the adductor magnus. In spite of this, injury to the adductor magnus is seldom reported, in stark contrast to frequent reports on injury of the adductor longus. Whether or not some of the injuries imputed to the adductor longus may actually include lesions of the adductor magnus is a topic that might merit consideration in sports medicine.

Electromyographic studies have shown the adductor magnus to be active during the loading response, terminal stance phases of the gait cycle (Lyons et al., 1983; Perry & Burnfield, 2010), during the ascent of stairs (Lyons et al., 1983), during the support phase and the swing phase in running (Wiemann & Tidow, 1995), and during the propulsive phase and the pulling phase in bicycling (Watanabe et al., 2009). Although electromyography is often an effective tool for elucidating the function of a muscle, morphological characteristics of the adductor magnus make it difficult to investigate. The bulk of its musculature is submerged beneath other muscles, so the portion accessible to surface electrodes is limited to the AM4, generally supplied by the tibial nerve portion of the sciatic nerve. Although fine-wire electrodes can be used to record activity from specific deeper muscles, precisely locating the AM1, AM2, or AM3 is not easy. Thus some 70% of the adductor magnus, supplied principally by the posterior branch of the obturator nerve, has been largely ignored.

Electromyographic studies of the accessible AM4 indicate that degree of myoelectric activity exhibited depends on angle of the hip joint (Okamoto et al., 1966). Considering that innervation of the adductor magnus proceeds in a stepwise fashion across its portions from the posterior branch of the obturator nerve to the tibial nerve portion of the sciatic nerve, the idea that all of the portions act in unison to produce a large force might better be replaced with the notion that selective activity in one portion or another may depend in great part on configuration at the hip joint. In addition, characteristics of hip motion as well as the load demanded are likely to contribute to determining how active a given portion or combination of portions would be at a given moment. More detailed knowledge of these phenomena could go a long way in explaining why the adductor magnus so often avoids injury.

Traditionally, the adductor magnus has been divided into a “hamstrings” part that attaches to the adductor tubercle at the distal end of the femur and that appears to receive its innervation entirely from the tibial nerve portion of the sciatic nerve, and an “adductor” part that attaches to the linea aspera of the femur and is allegedly supplied only by the posterior branch of the obturator nerve (Moore & Dalley, 2005; Standring, 2008). Given the definitions of the four portions of the adductor magnus used in the present study, the “hamstrings” part would correspond to the AM4 and the “adductor” part to the remaining three portions. In addition to our proposal for an alternative functional division of the portions of the adductor magnus, our findings concerning innervation likewise do not completely agree with the traditional idea, as the AM3 portion was shown to be supplied by both tibial and obturator nerves. Thus, on the basis not only of muscle architecture but also of peripheral nerve innervation, our results suggest that structure and function of the adductor magnus be reconsidered *in toto*. The traditional division of the adductor magnus into “hamstring” and “adductor” portions should no longer simply be taken without question.

Recently, magnetic resonance imaging has been used in investigations of activity or atrophy of the adductor magnus (Kawashima et al., 2004; Akima et al., 2005, 2007), but the muscle has invariably been observed *in toto*. The results of our study suggest that the adductor magnus should be looked upon as an assemblage of portions that may function differently from one another, such as the quadriceps femoris. Each portion of the adductor magnus may have its own role of activity depending on its dynamic circumstances.

Limitations of this study were that the material came from elderly people, so our results especially reflect the musculature of such people. Additionally, the specimens were fixed in formalin, which may have slightly altered the dimensions of what was measured (Friederich & Brand, 1990).

Perspective

The AM2, AM3, and AM4, having longer muscle fiber lengths than the AM1, appear to be, designed as displacers for moving the thigh through a large range of motion. The AM1 portion appears instead to be oriented principally toward stabilizing the hip joint. The adductor magnus should be looked upon as an assemblage of portions that may function differently from one another, such as the quadriceps femoris. Each portion of the adductor magnus may have its own role of activity depending on its dynamic circumstances.

Key words: adductor muscles, volume, muscle length, muscle fiber length, physiological cross-sectional area.

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