

ORIGINAL COMMUNICATION

Three-Dimensional Study of the Musculotendinous Architecture of Supraspinatus and Its Functional Correlations

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The supraspinatus is most frequently involved in shoulder pathology. However, the musculotendinous architecture of the supraspinatus has not been well documented. Therefore, the purpose of this study is to investigate the detailed three-dimensional architecture of the supraspinatus throughout its volume. Ten male formalin embalmed cadaveric specimens (mean age 61.9 ± 16 years) without any evidence of rotator cuff pathology were used. Three-dimensional coordinates (x , y , and z) of the tendon and muscle fiber bundles were collected in situ, using serial dissection and digitization. The data was reconstructed into a three-dimensional model using Maya™. Fiber bundle lengths, pennation angles (PA), muscle volumes, and tendon dimensions for each architecturally distinct area were computed and then analyzed using paired t -tests and ANOVA ($P < 0.05$). The supraspinatus was found to consist of anterior and posterior regions, which were each further subdivided into superficial, middle, and deep parts. Mean PA were found to be significantly different between the distinct parts of the anterior region of the muscle. Medial PA was also found to be significantly different between the superficial and middle, and superficial and deep parts of the posterior region. These results provide insight into the normal function of the muscle and its possible contribution to the initiation and progression of supraspinatus tendon tears. Clin. Anat. 20:648–655, 2007. © 2007 Wiley-Liss, Inc.

Key words: cadavers; modeling; 3D; rotator cuff; shoulder; muscle; tendon; angle; length; volume

INTRODUCTION

The supraspinatus, one of the four rotator cuff muscles, abducts the humerus and creates compressive forces to stabilize the glenohumeral joint (Wuelker et al., 1994; Burke et al., 2002). When there is injury or weakness of the supraspinatus, the normal balance of forces acting on the glenohumeral joint is disrupted (Graichen et al., 2000). In individuals over the age of 40, a rotator cuff tear involv-

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TABLE 1. Summary of Architectural Data Obtained From Cadaveric Studies of the Human Supraspinatus Muscle

Author (year)	n (sex)	Age	FBL (cm)	θ (deg)	MV (cm ³)	ML (cm)
Wood et al. (1989)	1 [1M]	—	—	—	39.3	8.6
Keating et al. (1993)	5	—	5.6 (4.7–6.5) ^a	—	23 (15–31)	—
Vahlsieck et al. (1994)	49	(52–97)	—	—	—	A:10.6 P:8.9
Jensen et al. (1995)	1	—	6.5 (6.0–7.5)	Sup: (20–25) Deep: (10–12)	36	11
Itoi et al. (1995)	11	—	2.8 ± 0.5	—	—	—
Juul-Kristensen et al. (2000b)	9 [F]	78.9 (55–87)	4.7 ± 1.1	11.4 ± 7.8	29.7 ± 11.6	—
Roh et al. (2000)	25 [10 M/15 F]	82	A:8.3 ± 0.9 (4.5–11.7) P:6.5 ± 1.2 (3.5–10.1)	A:14 ± 3 (8–20) P:10 ± 3 (2–20)	A:12 ± 4 (7–25) P:4 ± 2 (1–8)	—
Volk and Vangsness (2001)	20 [10 M/10 F]	(48–76)	—	—	—	14.5 (12.2–16.8)

FBL, Mean fiber bundle length; θ, mean pennation angle; MV, mean muscle volume; ML, mean muscle length; M, male; F, female; A, anterior; P, posterior; Sup, superficial.

—, Data not reported.

^aValues reported in parentheses indicate ranges.

ing the supraspinatus is one of the major causes of shoulder pain and functional deficit (Matsen, 2006).

Musculotendinous architecture—the arrangement of contractile and connective tissue elements within a muscle—is an important determinant of muscle function (Lieber and Fridén, 2001). Despite the prevalence and clinical importance of supraspinatus pathology, the relationship between supraspinatus architecture and shoulder function has not been well documented.

The musculotendinous architecture of the supraspinatus has been studied using cadaveric dissection (Tables 1 and 3), ultrasonography, and magnetic resonance imaging (Tables 2 and 3). These studies have been mostly descriptive and have focused on gross structure. Both Vahlsieck et al. (1993) in their MRI study, and Roh et al. (2000) in their cadaveric study, found supraspinatus divided into anterior and posterior elements. Anterior fiber bundles were found to be bipennate, while posterior fiber bundles demonstrated a more parallel arrangement. In addition, a long tubular intramuscular tendon/aponeurosis was found in the anterior portion of the muscle, but not in the posterior component.

However, these studies were limited by several factors. First, the location of fiber bundle sampling for calculating architectural parameters was not well documented. Second, architectural parameters, such as fiber bundle length, pennation angle, and tendon dimensions were measured in only a few of these studies. Third, in these studies, fiber bundle length was usually defined by an average value assigned to the entire muscle despite the distinctive divisions within the muscle. Lastly, pennation angles were measured manually in excised muscle with a goniometer rather than in situ.

To date, although the anterior and posterior components of supraspinatus have been identified, the musculotendinous architecture of these components has yet to be investigated in a three-dimensional fashion throughout the volume of the muscle. This has made functional correlation difficult. The purpose of this study is to investigate and quantify the three-dimensional musculotendinous architecture of supraspinatus throughout its volume.

METHODS

Specimens

Ten formalin embalmed human cadaveric specimens with a mean age of 61.9 ± 16 years were used for this study. Specimens with evidence of visible gross shoulder abnormality, previous surgery, or tendon pathology were excluded. Approximately 60–70% of dissected specimens were excluded due to tendon pathology. Only male specimens were used in this study, since all female specimens were excluded due to tendon pathology. Ethics approval was received from the Chief Coroner and General Inspector of Anatomy of the Province of Ontario and from the University of Toronto.

Dissection and Digitization

The supraspinatus was exposed by removing the superficial fascia and acromion. To prevent movement, the shoulder joint was fixated in 0° of abduction, flexion, and lateral rotation with a metal plate screwed to the humerus and scapula. Then the specimen was clamped into a securely mounted vice and three reference points (scapular spine, coracoid process, and greater tubercle) were demarcated with a screw.

TABLE 2. Summary of Architectural Data Obtained From Magnetic Resonance Imaging (MRI) and Ultrasonographic (US) Studies of Supraspinatus Muscle on Live Subjects

Author (year)	n (sex)	Age	ML (cm)	MT (cm)	MV (cm ³)
Juul-Kristensen et al. (2000a) [MRI & US]	8 [F]	39.8 (27–54) ^a	–	2.2 [MRI]; 2.0 [US]	–
Juul-Kristensen et al. (2000b) [MRI]	20 [F]	(22–58)	12.0 ± 0.6	–	48.3 ± 7.5

ML, Mean muscle length; MT, mean muscle thickness; MV, mean muscle volume; F, female.
–, Data not reported.

^aValues reported in parentheses indicate ranges.

These reference points were later used to reconstruct the specimen. Next, the periphery of the supraspinatus tendon was outlined with points using a paint pen. Each point was digitized using a Microscribe™ G2 Digitizer in order to obtain the *x*, *y*, and *z* coordinates of each point. The supraspinatus muscle belly was then serially dissected in situ with the aid of a dissection microscope. At each layer (1.5–2 mm in thickness), 10–60 fiber bundles were identified and traced from their medial to their lateral attachment sites. The attachment sites and 10–20 intervening points were digitized for each fiber bundle. Following digitization, fiber bundles were sequentially removed to expose the next layer. Digitization of the tendon periphery was repeated at every three to five layers of the muscle. After the muscle fibers were digitized and removed, the remaining tendon was cut at 5 mm intervals and the circumference was digitized.

Modeling

Digitized data was entered into Maya™ (Alias, Toronto, Canada—specialized software used in three-dimensional modeling and animation) that had been enhanced with additional software plug-ins developed in our laboratory. This allowed the supraspinatus muscle belly and tendon architecture to be viewed throughout its volume. Architecturally distinct parts of the muscle belly were identified and their tendinous attachments were determined. The morphology of internal and external tendons was investigated and documented.

Data Analysis

Fiber bundle lengths, pennation angles (PA), muscle volumes, and dimensions of intramuscular and extramuscular tendons were calculated using computer algorithms. Fiber bundle length was calculated as the sum of the distances between each of the digitized points along the fiber bundle and the pennation angle as the angle between the fiber bundle and line of force (Fig. 1). Line of force was defined to run precisely through the center of the muscle volume from origin to insertion. The angle of pennation measured in this study using three-dimensional computer modeling can be compared to previous two-dimensional studies that utilized a goniometer to measure pennation angle. This comparison can be made because in this study the instantaneous measurement of angles uses two vectors at a time, one defining a tangent to the fiber bundle and the other representing the path of the line of force. As a result, the angles are measured within a single plane. Fiber bundle

length, PA for the medial and lateral ends of the fiber bundles, and volume of architecturally distinct parts of the muscle were characterized with descriptive statistics (mean, standard deviation, and range). Paired *t*-tests and ANOVA followed by Tukey's post-hoc test were carried out to compare means. Statistical significance was set at *P* < 0.05.

RESULTS

Tendon Morphology

The tendon of insertion consisted of an anterior and posterior tendon found in all 10 specimens (Fig. 2).

The quadrangular shaped posterior tendon was found on the lateral aspect of supraspinatus. The posterior tendon blended with the fibrous layer of the capsule of the shoulder joint and terminated by inserting onto the postero-superior aspect of the greater tubercle of the humerus. The only muscular attachment to the posterior tendon was to its medial aspect. In three specimens, a distinct short intramuscular tendinous slip (1.0 ± 0.2 cm) extended medially from the posterior tendon. The average width of the posterior tendon was 1.6 ± 0.3 cm and the average length is 2.9 ± 0.6 cm (Table 4).

The cord-like anterior tendon, like the posterior tendon, blended with the joint capsule, but then attached to the antero-superior aspect of the greater tubercle of the humerus. The length of the anterior intramuscular tendon was found to be significantly longer and narrower than the posterior tendon (*P* < 0.05). The average width of the anterior tendon was 0.8 ± 0.2 cm; the average length of the anterior tendon was 6.1 ± 0.7 cm (Table 4). Laterally, the anterior tendon was extramuscular, but became intramuscular medially.

Muscle Morphology

The muscle belly was partitioned into two large architecturally distinct regions, anterior and posterior, which could be further subdivided into superficial, middle, and deep parts based on attachment sites and architectural parameters (Fig. 2). In some cases, an additional small anterior part was identified in the posterior region.

Anterior and posterior regions were found in all 10 specimens. The average volume of the anterior region was 15.4 ± 5.7 cm³, while the average volume of the posterior region was 2.5 ± 0.7 cm³ (Table 6). The large anterior region fills approximately the anterior three quarters of the supraspi-

TABLE 3. Summary of Architectural Data of the Human Supraspinatus Tendon

Author (year)	Study type	n (sex)	Age	Length (cm)	Width (cm)	Thickness (cm)
Gagey et al. (1990)	MRI	30	—	A: (5–8) ^a P: (0.5–1)	—	—
Vahlensieck et al. (1993)	MRI	20 [8 M/12 F]	40.5 ± 13.9	P: 6.2 ± 1.1	—	—
Vahlensieck et al. (1994)	Cad	49	(52–97)	—	P: 2.4 ± 0.4	—
Itoi et al. (1995)	Cad	11	—	A: 2.3	—	—
Roh et al. (2000)	Cad	25 [10 M/15 F]	82	—	A: 0.8 ± 0.2 (0.5–1.3); P: 1.3 ± 0.3 (0.7–1.6)	A: 0.3 ± 0.07 (0.2–0.4); P: 0.3 ± 0.07 (0.2–0.4)
Volk and Vangsness (2001)	Cad	20 [10 M/10 F]	(48–76)	A: 5.4 (4.1–7.7); P: 2.8 (2–3.7)	—	—
Dugas et al. (2002)	US	20	63 (48–88)	1.3 ± 0.6 (0.7–1.5)	1.6 ± 0.6 (1.0–2.1)	—

Mean tendon length, width, and thickness are reported. MRI, magnetic resonance imaging; Cad, cadaveric; US, ultrasonography; M, male; F, female; A, anterior; P, posterior. —, Data not reported.

^aValues reported in parentheses indicate ranges.

nous fossa, while the posterior region located dorsally in the supraspinous fossa is partially overlapped by the anterior region. These regions were defined by their lateral attachments: fiber bundles of the anterior region attached to the anterior tendon; fiber bundles of the posterior region attached to the posterior tendon. In three specimens, the anterior portion of the posterior region formed a distinct bipennate muscle segment, which attached to the intramuscular tendinous slip of the posterior tendon described above. This was found only in three of the youngest specimens (<50 years of age).

The morphologies of the subdivisions of the anterior and posterior regions (superficial, middle, and deep) are described below.

Anterior region

- The fiber bundles of the anterior superficial part (AS) attached medially to two sites: (1) the anteromedial border of the supraspinous fossa and (2) the medial third of the superior border of the scapular spine. The fiber bundles from each medial attachment converged to attach to the periphery and superficial surface of the anterior tendon (Figs. 2A and 2B).
- The anterior middle part (AM), more deeply situated, extended from the medial two-thirds of the supraspinous fossa to get attached to the deep surface of the medial half of the anterior tendon. Fiber bundles of the middle part joined the anterior tendon in a bipennate fashion (Figs. 2C and 2D).
- The fiber bundles of the anterior deep part (AD) were parallel in arrangement and spanned between the lateral third of the supraspinous fossa and the deep surface of the lateral half of the anterior tendon (Figs. 2E and 2F).

Posterior region

- The fiber bundles of the posterior superficial part (PS) were directed antero-laterally from the posterior wall of the supraspinous fossa to the medial border of the

posterior tendon. A clear cleavage plane separated the PS from the underlying posterior middle part (Figs. 2G and 2H).

- The fiber bundles of posterior middle part (PM) attached medially to the posterior wall of the supraspinous fossa and laterally to the medial border of the posterior tendon (Figs. 2I and 2J).
- The posterior deep part (PD) is located deep and anterior to the PM. Fiber bundles attached medially to the base of the supraspinous fossa and laterally to the medial border of the posterior tendon (Figs. 2I and 2J).

The mean fiber bundle lengths were similar throughout the volume of the muscle, with exception of the posterior region; the mean fiber bundle length of the middle part was significantly greater than the deep part ($P < 0.05$). The

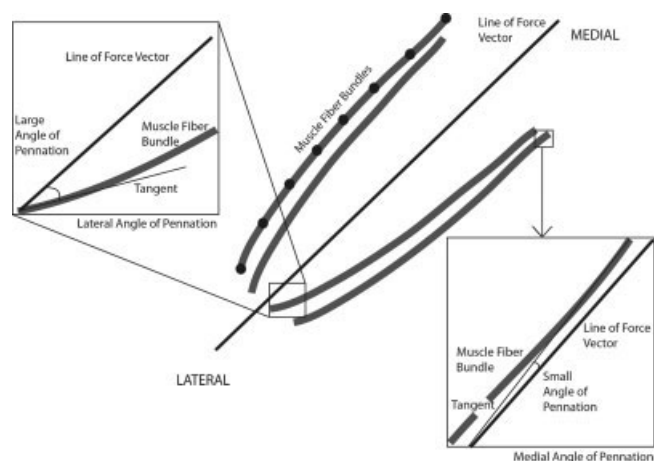


Fig. 1. Calculation of muscle fiber bundle length, and medial and lateral pennation angle.

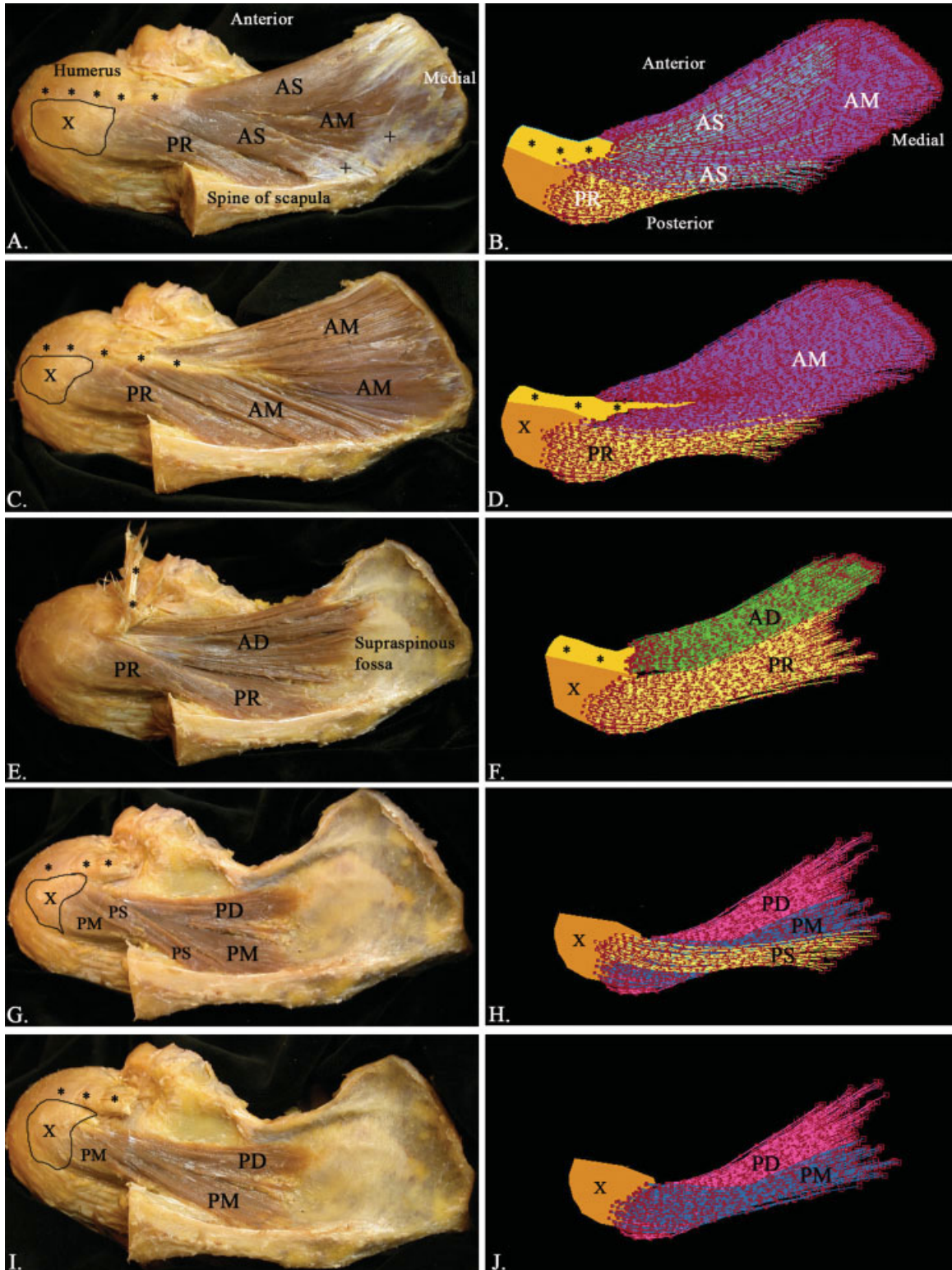


Fig. 2. Dissection and three-dimensional modeling of the architecturally distinct regions of left shoulder supraspinatus, superior views. **A, B:** Superficial part of anterior region (AS) and entire posterior region (PR). **C, D:** Middle part of anterior region (AM). **E, F:** Deep part of anterior region (AD). The anterior part (*) of the supraspinatus tendon is reflected. **G, H:** Superficial (PS), middle (PM) and deep (PD) parts of the posterior region. **I, J:** Middle (PM) and deep (PD) parts of the posterior region. Anterior part of supraspinatus tendon (*); posterior part of supraspinatus tendon (X); medial aponeurosis (+).

TABLE 4. Summary of Mean Tendon Dimensions of Supraspinatus

Part of tendon	<i>n</i>	Length (cm)	Width (cm)
Anterior	8 ^a	6.1 ± 0.7 (5.0–6.9) ^b	0.8 ± 0.2 (0.6–1.0)
Posterior	8 ^a	2.9 ± 0.6 (2.3–4.0)	1.6 ± 0.3 (1.2–2.1)

Mean length and width for the anterior and posterior parts of supraspinatus tendon are reported.

^aTendon data was not collected from the first two digitized specimens.

^bValues reported in parentheses indicate ranges.

TABLE 5. Summary of Mean Architectural Parameters for Subdivisions of the Anterior and Posterior Regions of Supraspinatus Muscle

Part of muscle	<i>n</i>	FBL (cm)	θL (deg)	θM (deg)
Anterior region				
Superficial part	10	6.7 ± 0.5 ^a (5.7–7.5) [*]	64.6 ± 12.7 ^a (44.6–79.0)	11.4 ± 2.8 ^a (6.6–15.5)
Middle part	10	6.6 ± 0.6 ^a (5.7–7.9)	51.4 ± 13.1 ^{a,b} (34.3–70.0)	9.8 ± 2.3 ^a (7.6–14.5)
Deep part	10	6.6 ± 0.6 ^a (5.4–7.4)	74.1 ± 10.2 ^{a,c} (54.9–86.0)	16.8 ± 6.1 ^b (9.5–30.6)
Posterior region				
Superficial part	10	6.9 ± 0.9 ^d (5.2–7.9)	84.4 ± 3.1 ^d (78.6–88.5)	18.6 ± 7.6 ^d (7.9–31.9)
Middle part	10	7.0 ± 0.6 ^{d,e} (6.2–8.1)	82.0 ± 4.3 ^d (74.0–86.2)	11.3 ± 4.6 ^e (6.7–20.7)
Deep part	10	6.2 ± 0.5 ^{d,f} (5.4–7.2)	82.5 ± 4.9 ^d (75.6–88.8)	11.2 ± 3.6 ^e (6.6–19.7)

FBL, mean fiber bundle length; θL, mean lateral pennation angle; θM, mean medial pennation angle are reported for the architecturally distinct regions and parts of supraspinatus muscle. The superscript letters are used to indicate the presence or absence of statistical significance (analysis of variance) between the anterior or posterior regions. If the superscript letters in a column block differ, then the result is statistically significant. If the letter is repeated, there is no statistical significance. Note: statistical comparison was only made within each region and not between.

*Values reported in parentheses indicate ranges.

range of mean fiber bundle length was between 6.2 ± 0.5 cm and 7.0 ± 0.6 cm (Table 5).

The mean lateral angle of pennation was greater than the mean medial angle of pennation in all parts of the muscle (Table 5). In the anterior region, the mean lateral pennation angle (θ_L) for the middle part was significantly less than the deep part (*P* < 0.05); however, the superficial part was not different when compared to the middle and deep parts. The mean medial pennation angle (θ_M) of the deep part was significantly greater when compared to both the superficial and middle parts (*P* < 0.05); there was no statistical difference between the superficial and middle parts (Table 5). In the posterior region, no significant difference was found in the lateral PA (θ_L) among the superficial, middle, and deep parts. However, the mean medial pennation angle (θ_M) of the superficial part was significantly greater than the middle and deep parts (*P* < 0.05); no difference was found between the middle and deep parts (Table 5).

DISCUSSION

The musculotendinous architecture of the supraspinatus is complex with the muscle having not only an anterior and posterior region but also subdivisions within each region. Furthermore, each region has a distinct bony or tendinous attachment. This study is the first of its kind to quantify and document architectural parameters of the supraspinatus, in situ, using novel three-dimensional modeling techniques. Parameters were obtained as means taken from about 1200–1600 fiber bundles per specimen throughout the entire muscle volume.

Few previous studies have documented the morphology of the tendon and muscle architecture (Tables 1, 2, and 3). Individual studies seldom include enough parameters, making it difficult to conceptualize structure of the entire muscle. Moreover, in the more detailed studies of Jensen et al. (1995) and Roh et al. (2000), the location of fiber bundle sampling within the anterior and posterior regions was not specified; this makes comparison of results challenging. Furthermore, in these studies the fiber bundles were not measured in situ.

Tendon Morphology

The anterior and posterior parts of the supraspinatus tendon found in this study were also documented by Volk and Vangsness (2001), Roh et al. (2000), and Gagey et al. (1990). These studies measured either tendon length (Gagey et al., 1990; Volk and Vangsness, 2001) or tendon width (Roh et al., 2000), but not both. In all studies, the anterior tendon length was found to be greater than the posterior tendon length. The anterior tendon length found in this study (6.1 cm ± 0.7 cm) was comparable to data reported by Volk and Vangsness (2001) and Gagey et al. (1990); 5.4 and 5–8 cm, respectively. Posterior tendon length reported by Gagey et al. (1990) was markedly shorter (0.5–1 cm) than averages reported in this study and those by Volk and Vangsness (2001); 2.9 ± 0.6 cm and 2.8 cm, respectively. This difference may be attributed to how the posterior tendon was defined. Both anterior and posterior tendon widths were only previously reported by Roh et al. (2000) and were found to be 0.8 ± 0.2 cm and 1.3 ± 0.3 cm, respectively. These widths were analogous to

TABLE 6. Summary of Mean Architectural Parameters for the Regions of Supraspinatus Muscle

Region of muscle	<i>n</i>	FBL (cm)	θL (deg)	θM (deg)	Vol (cm ³)
Anterior region	10	6.7 ± 0.7 (5.8–7.9) ^a	60.0 ± 12.0 (41.8–74.5)	11.8 ± 2.7 (8.5–16.6)	15.4 ± 5.7 (6.2–26.6)
Posterior region	10	6.7 ± 0.5 (5.7–7.6)	82.2 ± 4.0 (74.7–85.9)	12.4 ± 3.6 (7.1–18.4)	2.5 ± 0.7 (1.4–3.8)

FBL, mean fiber bundle length; θL, mean lateral pennation angle; θM, mean medial pennation angle; Vol, volume are reported for the architecturally distinct regions of supraspinatus muscle.

^aValues reported in parentheses indicate ranges.

those found in this study where the anterior width was 0.8 ± 0.2 cm and the posterior 1.6 ± 0.3 cm.

A small tendinous slip, extending ~1 cm from the posterior tendon, was found in three of the youngest (<50 years of age) specimens. Vahlensieck et al (1993), in an MRI study of subjects with a mean age of 40.5 ± 13.9 years, found similar tendinous slips. Other cadaveric studies have not documented this structure, but it should be noted that the specimens were obtained from older subjects (Table 1). Since the intramuscular tendinous slip was short and found deep to the anterior region of the muscle belly it also could have been overlooked in previous studies that did not dissect into the entire muscle volume. Further study is needed to determine if the presence of this tendon and its associated bipennate fiber bundles are correlated with age. A force analysis study of the different regions and distinct parts of supraspinatus would aid in better understanding the significance of this tendinous slip.

Muscle Morphology

The anterior and posterior regions of the supraspinatus muscle were found in all ten specimens used in this study. Similarly, Roh et al. (2000), Gagey et al. (1990) and Vahlensieck et al. (1994) also reported these two distinct regions in all specimens investigated. However, Volk and Vangsness (2001) only found a distinct anterior and posterior region in 7 of the 20 specimens examined.

The volumes of the anterior (15.4 ± 5.7 cm³) and posterior (2.5 ± 0.7 cm³) regions found in this study concur with Roh et al. (2000) who found an average anterior volume of 12 ± 4 ml and a posterior volume of 4 ± 2 ml. However, other studies that have reported the volume of the entire muscle had larger volumes ranging from 23.0–39.3 ml (Table 1). This large discrepancy may be explained by the precision of the various methods used to obtain volume data among the different studies.

The mean fiber bundle lengths of the anterior (6.7 ± 0.7 cm) and posterior (6.7 ± 0.5 cm) regions of the supraspinatus muscle in this study were found to be very similar. Contrary to these findings, Roh et al. (2000) found the mean fiber bundle length of the anterior region (8.3 ± 0.9 cm) of the supraspinatus to be significantly longer than the mean fiber bundle length of the posterior region (6.5 ± 1.2 cm). Other investigators have found average fiber lengths for the entire muscle ranging from 2.8–6.5 cm (Table 1).

When previous studies have recorded PA, only one angle was reported, presumably from the medial side. The medial pennation angle found by Roh et al. (2000) was (14 ± 3)° and (10 ± 3)° for the anterior and posterior region, respectively. The medial PA of the anterior (11.8 ± 2.7)° and posterior (12.4 ± 3.6)° regions of this study were similar to those reported by Roh et al. (2000). Juul-Kristensen et al.

(2000b) calculated an average pennation angle of (11.4 ± 7.8)° for the entire muscle belly. In this study, medial PA were less than the lateral PA for both the anterior and posterior regions (Table 6). During the generation of force, the lateral sides of the fiber bundles are expected to have less impact on the force of contraction because they are not as parallel to the line of force in comparison to the medial side with smaller angles of pennation.

Unique to this study, architecturally distinct regions (superficial, middle, and deep) were observed within the anterior and posterior regions of the muscle belly. These parts were defined by their distinct attachment sites. The average fiber bundle length among all the parts did not differ markedly (range, 6.2 ± 0.5 cm to 7.0 ± 0.6 cm). Unlike most muscles where the deepest fiber bundles are often the shortest; in the supraspinatus, the deep fiber bundles from both the anterior and posterior region originate more laterally than the superficial fiber bundles but also insert more laterally. As a result, the lengths of the fiber bundles do not change significantly from superficial to deep.

Clinical Implications

The significantly larger volume of the anterior region of muscle belly suggests that much of the muscle's force is produced by this region. As a result, the anterior tendon may undergo greater stress than the posterior tendon during contraction. This may lead to the higher incidence of anterior tendon tears (Huang et al., 2005).

Since the PA was significantly different between the different parts of the anterior region, stresses throughout the anterior tendon are heterogeneous. For example, Huang et al. (2005) found intratendinous shear to occur within the tendon, with higher strain on the articular (deep) side of the tendon. Although joint position has been found to have a pronounced effect on intratendinous strain and on rotator cuff mechanics (Bey et al., 2002), the influence of the musculotendinous architecture on intratendinous shearing has not been discussed. However, the larger pennation angle of the deep part when compared to the middle part of the anterior region suggests that the middle part will generate greater force than the deep part under similar activation conditions. As a result, the different contraction forces stressing the tendon simultaneously may contribute to greater shear stresses to the articular surface of the anterior tendon.

The three-dimensional architecture of supraspinatus defined in this study can be utilized to investigate the dynamic function of each architecturally distinct region/part. For example, ultrasonography, which has been used to investigate the dynamic musculotendinous architecture of other muscles such as soleus (Chow et al., 2000), may be applied to supraspinatus. Additionally, electromyography

(EMG) studies can be planned using the architectural map developed in this study. Therefore, the results of this study can be utilized better understand the normal and pathologic function of supraspinatus in vivo.

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