Qualitative and Quantitative Anatomy of the Proximal Humerus Muscle Attachments and the Axillary Nerve: A Cadaveric Study

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Purpose: To provide a quantitative and qualitative anatomic analysis of the pectoralis major, teres major, and latissimus dorsi on the humerus, as well as the deltoid tendinous attachments on the proximal humerus and acromion, and to quantitatively characterize the humeral course of the axillary nerve. **Methods:** Ten nonpaired, fresh-frozen human cadaveric shoulders were analyzed. A portable coordinate-measuring device quantified the location of bony landmarks and tendon attachment areas. The tendon footprints were recorded by tracing their outlines and center points. The footprint areas of the tendons, the distances between the footprint areas and pertinent osseous and soft-tissue landmarks, and the distance between where the axillary nerve courses across the humerus relative to the acromion and greater tuberosity were measured. **Results:** Of the 10 specimens, 9 (90%) had 5 distinct tendinous bands attaching the deltoid to the acromion; 1 specimen had 4 bands. The distances between the center of the deltoid footprint on the humerus and the centers of the pectoralis major, latissimus dorsi, and teres major tendon footprints on the humerus were 43.5 mm, 58.5 mm, and 49.4 mm, respectively. The shortest distances from the perimeter of the pectoralis major to the latissimus dorsi and teres major tendon footprints were 3.9 mm and 9.5 mm, respectively. The distance from the superior aspect of the greater tuberosity to the axillary nerve on the humeral shaft was 50.3 mm (95% confidence interval, 47.0-53.5 mm). The distance from the lateral acromion to the axillary nerve was 69.3 mm (95% confidence interval, 64.1-74.5 mm). **Conclusions:** The deltoid muscle had 4 to 5 tendinous insertions on the acromion, and the axillary nerve was 50.3 mm from the tip of the greater tuberosity. The distance between the lower border of the pectoralis major and the axillary nerve was 9.4 mm. **Clinical Relevance:** Knowledge of the quantitative anatomy of the tendons of the proximal humerus and axillary nerve can aid in identifying structures of interest during open shoulder surgery and in avoiding iatrogenic axillary nerve injury. Furthermore, this study provides direction to avoid injury to the deltoid tendons during open surgery.

Despite the growth of arthroscopic shoulder surgery, open surgical approaches to the shoulder remain vital for a variety of pathologies, including tendon transfer surgery for massive or irreparable rotator cuff tears,[1] fixation for proximal humeral fractures,[2] management of tears of the latissimus dorsi and

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teres major tendons,[3,4] management of pectoralis major tendon tears,[5,6] and shoulder arthroplasty.[7] A thorough understanding of the anatomy of the deltoid muscle and various tendon insertions on the proximal humerus, as well as the course of the axillary nerve, is critical for performing open and minimally invasive shoulder surgery safely and efficiently.

Several techniques for muscle-tendon transfer have been reported to treat irreparable rotator cuff tears.[1] Transfers of the latissimus dorsi[8-12] and pectoralis major[13,14] are the most commonly described techniques. Other tendon transfer techniques described for treating massive rotator cuff tears or failed rotator cuff repair include the deltoid flap procedure[15,16] and teres major transfer.[17] Although the anatomy of the rotator cuff tendon attachments on the proximal humerus has been well described,[18-23] the anatomic relations between the attachments of the deltoid, pectoralis major, latissimus dorsi, and teres major tendons on the proximal humerus, to our knowledge, have only been studied qualitatively.

In addition to the various tendon attachments on the proximal humerus, understanding the anatomy and course of the axillary nerve is critical for avoiding iatrogenic injury during open shoulder surgery. An assessment of both qualitative and quantitative anatomy relevant to these structures would aid surgeons in performing tendon transfer procedures. Thus the purposes of this study were to provide a quantitative and qualitative anatomic analysis of the pectoralis major, teres major, and latissimus dorsi on the humerus, as well as the deltoid tendinous attachments on the proximal humerus and acromion, and to quantitatively characterize the humeral course of the axillary nerve. We hypothesized that the musculotendinous structures in the shoulder and the course of the axillary nerve would have definable parameters concerning their anatomic attachments and consistent relations to pertinent landmarks.

Methods

Specimen Preparation

Ten nonpaired, fresh-frozen human cadaveric shoulders with no prior injury, no surgical history, and no gross anatomic abnormality (mean age, 52 years; age range, 33-64 years; 5 female and 5 male specimens; 5 right and 5 left shoulders) were included in this study. All specimens were stored at −20°C and thawed at room temperature for 24 hours before preparation. The cadaveric specimens used in this study were donated to a tissue bank for medical research and then purchased by our institution. Our institution (Vail Valley Medical Center/Vail Health IRB) does not require institutional review board approval for cadaveric studies. All dissections were performed by 2 board-certified orthopaedic surgeons (J.C. and G.M.). The humeral diaphyses were cut 15 cm from the shoulder joint line. All soft tissue within 10 cm of the joint line was preserved. The acromioclavicular joint was fixed with 2 Kirschner wires with the clavicle in its anatomic position, which was verified by 3 orthopaedic surgeons (G.M., J.C., M.B.F.) by judging its congruency. The scapula and humerus were then fixed in a clamp to avoid any further movement during data collection. The humeral head was additionally transfixed to the glenoid with the humerus in a neutral position to avoid movement during data collection (Fig 1). The position of the humeral head relative to the scapula did not affect the measurements because the coordinate frame was built on the humerus, and none of the measurements taken on the humerus were referenced to the clavicle or scapula.

Quantitative Measurements

Coordinate frame blocks were positioned and secured at locations on the distal aspect of the humeral shaft. These blocks served as consistent reference points for all subsequent measurements. A portable coordinate-measuring device (7315 Romer Absolute Arm; Hexagon Metrology, North Kingstown, RI) was used to quantify the location of pertinent bony landmarks and tendon attachment areas. The robotic arm used in this study has ± 0.025 mm of point repeatability and ± 0.037 mm of volumetric accuracy, and variability among specimens was minimal. The tendons of each muscle were identified and sharply dissected from bone. The perimeters and center points of the footprints were immediately recorded with the measuring probe. In addition, all pertinent osseous landmarks were identified and their 3-dimensional static coordinates

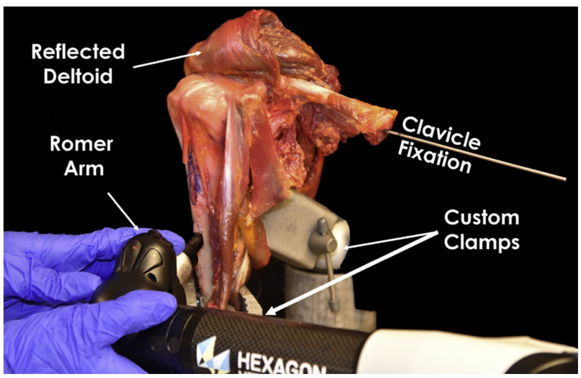

Fig 1. Setup. The scapula and humerus were fixed in custom-made clamps to ensure their position did not change during data collection, the acromioclavicular joint was transfixed with Kirschner wires, and the glenohumeral joint was fixed in a neutral position. A Romer arm was used to collect data points. At the end of data collection, a control measurement was taken on coordinate blocks to ensure the specimen did not move during data collection.

Table 1. Distances Between Bony Points of Acromion and 5 Tendon Bands of Deltoid Muscle, as well as Distances Between 5 Tendon Bands of Deltoid

	Distance to Center of TB 1, mm			Distance to Center of TB 2, mm			Distance to Center of TB 3, mm			Distance to Center of TB 4, mm			Distance to Center of TB 5, mm			Distance to Deltoid Center Point, mm		
		95% CI			95% CI			95% CI			95% CI			95% CI			95% CI	
	Mean	LB	UB	Mean	LB	UB	Mean	LB	UB	Mean	LB	UB	Mean	LB	UB	Mean	LB	UB
Distance from acromial point																		
Anterior	9.7	7.5	11.9	15.6	12.0	19.2	23.5	20.4	26.5	32.1	28.8	35.4	39.3	35.4	43.2	7.7	5.9	9.5
AL	5.3	3.3	7.3	7.6	5.1	10.0	17.2	13.9	20.5	27.7	23.8	31.7	37.5	33.1	41.9	6.8	6.1	7.5
Lateral	21.2	18.7	23.7	12.1	9.5	14.7	4.3	2.6	6.1	10.8	7.9	13.7	21.9	18.0	25.8	21.8	20.1	23.6
PL	38.0	34.4	41.6	30.4	26.8	33.9	20.4	17.3	23.5	10.2	7.5	12.9	5.0	2.5	7.4	38.5	35.1	41.9
PM	42.3	38.0	46.5	37.9	33.4	42.4	30.7	26.8	34.5	24.0	20.8	27.2	17.0	13.1	21.0	42.3	38.0	46.5
Distance from deltoid TB																		
TB 1	—	—	—	10.5	9.0	12.0	20.4	18.4	22.4	30.5	27.5	33.5	39.6	35.9	43.2	—	—	—
TB 2	—	—	—	—	—	—	11.0	9.9	12.1	21.9	19.8	24.0	32.6	29.3	35.9	—	—	—
TB 3	—	—	—	—	—	—	—	—	—	11.2	9.0	13.5	22.5	19.6	25.3	—	—	—
TB 4	—	—	—	—	—	—	—	—	—	—	—	—	12.8	10.8	14.8	—	—	—

NOTE. The anterior attachment was defined as the portion of the deltoid attaching medial to the anterolateral corner of the acromion, including the clavicle. The lateral attachment was defined as the portion attaching to the lateral aspect of the acromion between the anterolateral corner and posterolateral corner of the acromion. The posterior deltoid was defined as attaching medial to the posterolateral corner of the acromion on the scapula.

AL, anterolateral; CI, confidence interval; LB, lower bound; PL, posterolateral; PM, posteromedial; TB, tendinous band of deltoid on acromion; UB, upper bound.

recorded. The coordinates of each of the identified points were used to calculate the areas of the insertion sites and distances between the different center points and relevant osseous landmarks. The structures of interest were the deltoid muscle, including its origin and insertion; the insertions of the pectoralis major, latissimus dorsi, and teres major tendons; the course of the anterior branch of the axillary nerve on the humerus; and the bicipital groove.

Data Analysis

Data were analyzed with custom software (MATLAB 2008b; The MathWorks, Natick, MA). Distance measurements were collected as the 3-dimensional linear distance between structures and are referred to as direct distances. Unless otherwise noted, all anatomic distance measurements were made between the center points of corresponding structures. Cross-sectional areas were computed by projecting points taken along the circumference of the attachment onto an interpolated plane and calculating the area of the resulting 2-dimensional polyhedron. All results are expressed as means with 95% confidence intervals (CIs) (lower bound to upper bound). Distances are reported in millimeters, and areas are reported in square millimeters.

Results

Deltoid Muscle

The deltoid muscle inserted on the deltoid tuberosity of the humerus with an attachment that was notably larger than the insertions of the pectoralis major, latissimus dorsi, or teres major tendons on the humeral shaft. Proximally, the deltoid originated from the lateral aspect of the clavicle, acromion, and scapular spine. On the lateral aspect of the acromion, the deltoid muscle attached to the bone through 4 to 5 tendinous bands (Fig 1). The broadest attachments of the deltoid were on the anterior and lateral aspects of the acromion. Of the 10 specimens, 9 (90%) had 5 identifiable distinct bands within the deltoid muscle attaching to the anterior and lateral aspect of the acromion, whereas the tenth specimen had 4 bands (Table 1, Fig 2). The areas of each of these tendon insertion footprints on the acromion were relatively equivalent to one another across all specimens (Table 2).

The deltoid muscle inserted on the deltoid tuberosity 21.8 mm and 18.1 mm lateral to the medial and lateral borders of the bicipital groove, respectively. The center of the footprint was 70.1 mm (95% confidence interval [CI], 64.6-75.7 mm) from the axillary nerve. The distances between the center of the deltoid footprint and the centers of the pectoralis major, latissimus dorsi, and teres major footprints were 43.5 mm, 58.5 mm, and 49.4 mm, respectively

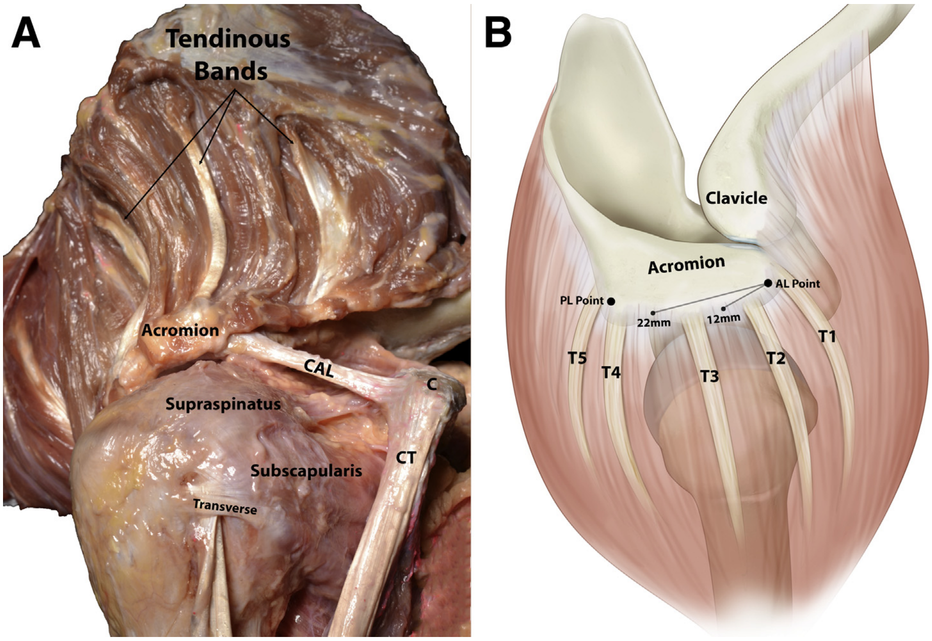

Fig 2. (A) A finely dissected right cadaveric shoulder with the deltoid muscle reflected medially from the acromion to show the individual tendinous bands of the deltoid observed. (B) A right shoulder showing the deltoid muscle and the 5 tendinous bands (T1-T5) inserting on the acromion. These bands provide a strong attachment of the deltoid proximally and should be preserved or sutured back during open shoulder surgery. The "safe zone" middle point is demarcated at 12 mm and at 22 mm from the anterolateral (AL) point. (C, coracoid; CAL, coracoacromial ligament; CT, conjoint tendon of biceps brachii and coracobrachialis; PL, posterolateral.)

(Table 3). The distance from the center of the deltoid footprint to the center of the greater tuberosity was 101 mm (Table 3), whereas the shortest distance between the perimeters of the deltoid attachment and the greater tuberosity was 57 mm.

Table 2. Mean Areas of Tendon Footprint Attachments and Bony Landmarks With 95% CIs

	Area, mm^2		
		95% CI	
Humerus Structure	Mean	LB	UB
Musculature			
Deltoid	732.4	621.4	843.3
Pectoralis major	148.4	126.9	169.8
Latissimus dorsi	113.2	82.2	144.2
Teres major	131.5	104.2	158.8
Osseous landmark			
Lesser tuberosity	237.2	189.0	285.4
Greater tuberosity	680.2	519.1	841.2
Acromion			
Deltoid			
Anterior	93.4	61.6	125.2
Lateral	211.3	176.4	246.1
Posterior	416.0	333.3	498.6
TB 1 (n = 10)	29.8	25.1	34.6
TB 2 (n = 10)	21.9	17.3	26.6
TB 3 (n = 10)	26.1	21.3	31.0
TB 4 (n = 10)	26.0	21.9	30.2
TB 5 (n = 9)	31.2	22.7	39.7

NOTE. The anterior attachment was defined as the portion of the deltoid attaching medial to the anterolateral corner of the acromion, including the clavicle. The lateral attachment was defined as the portion attaching to the lateral aspect of the acromion between the anterolateral corner and posterolateral corner of the acromion. The posterior deltoid was defined as attaching medial to the posterolateral corner of the acromion on the scapula.

CI, confidence interval; LB, lower bound; TB, tendinous band of deltoid on acromion; UB, upper bound.

Attachment Areas

The footprint attachment areas of the tendons of interest are reported in Table 2. The deltoid attachment area on the humerus (mean, 732 mm^2; 95% CI, 621.4-843.3 mm^2) was between 4.9 and 6.5 times greater than the humeral attachment areas of the pectoralis major, latissimus dorsi, and teres major tendon attachments. The mean area of the pectoralis major insertion was 148.4 mm^2, whereas the latissimus dorsi footprint was 113.2 mm^2 and the teres major footprint was 131.5 mm^2.

The mean deltoid insertion area was 93.4 mm^2 on the anterior aspect of the acromion and 211.3 mm^2 on the lateral aspect of the acromion. Together, these 2 regions of deltoid origin accounted for 47.2% (95% CI, 38.5%-55.9%) of the deltoid's proximal attachment. The mean area of each individual deltoid band tendinous attachment on the acromion ranged between 21.9 mm^2 and 31.2 mm^2 across all 5 tendons.

Distances. The distances between the center points of all tendons and osseous landmarks of the acromion are presented in Table 1, center-point distances related to the humeral shaft are presented in Table 3, and the shortest distances between the perimeters of pertinent structures are presented in Table 4. It should be noted that the "shortest" distance between structures was measured from the edge of each structure's perimeter. The distance between the center of the lesser and greater humeral tuberosities was a mean of 30.9 mm

Table 3. Distances Between Center of Bony Landmarks of Humerus and Center of Humeral Tendon Attachments of Deltoid, Pectoralis Major, Latissimus Dorsi, and Teres Major Tendons and Distances Between Center Points of Tendinous Attachments

	Distance to Center of Humeral Deltoid, mm			Distance to Center of Pectoralis Major, mm			Distance to Center of Latissimus Dorsi, mm			Distance to Center of Teres Major, mm		
		95% CI			95% CI			95% CI			95% CI	
	Mean	LB	UB	Mean	LB	UB	Mean	LB	UB	Mean	LB	UB
Distance from center of lesser tuberosity	104.9	99.1	110.6	61.5	55.2	67.8	47.5	45.1	49.8	58.8	53.9	63.8
Distance from center of greater tuberosity	101.0	95.3	28.6	61.0	55.7	66.2	50.0	46.6	53.4	61.1	56.9	65.2
Distance from center of humeral deltoid	—	—	—	43.5	37.5	49.5	58.5	51.4	65.5	49.4	43.5	55.3
Distance from center of pectoralis major	—	—	—	—	—	—	17.8	12.2	23.4	16.4	14.0	18.8
Distance from center of latissimus dorsi	—	—	—	—	—	—	—	—	—	15.7	11.9	19.5

CI, confidence interval; LB, lower bound; UB, upper bound.

(95% CI, 29-32.8 mm), whereas the shortest distance between them was 9.4 mm (95% CI, 8-10.8 mm).

Pectoralis Major. The pectoralis major tendon was broad and flat and had 2 layers representing the sternal and clavicular aspects of the pectoralis major, which were fused distally (starting from 33.3-43.7 mm medial to the humeral insertion) and inserted on the humerus, lateral to the bicipital groove (Fig 3). The pectoralis major tendon inserted 3.5 mm and 0.8 mm lateral to the medial and lateral border of the bicipital groove, respectively. The insertion was 46.0 mm (95% CI, 37.4-54.4 mm) in length, parallel to the lateral border of the bicipital groove and the axis of the humerus. The distances between the center of the pectoralis major tendon footprint and the centers of the latissimus dorsi and teres major footprints were 17.8 mm and 16.4 mm, respectively (Table 3). The distance between the lower border of the pectoralis major and the axillary nerve was 9.4 mm (95% CI, 5.3-13.5 mm).

Latissimus Dorsi. The latissimus dorsi inserted between the pectoralis major and teres major tendons on the humerus, with the biceps tendon and bicipital groove running between the pectoralis major and latissimus dorsi tendon attachments. The latissimus dorsi tendon itself was narrower just before its insertion on bone because the tendon fibers fanned out into a broader humeral insertion (Fig 4).

The latissimus dorsi tendon inserted 0.6 mm and 4.7 mm from the medial and lateral borders of the bicipital groove, respectively. The insertion was 37.1 mm (95% CI, 32.7-41.4 mm) in length, parallel to the medial border of the bicipital groove. The distance between the center of the latissimus dorsi tendon footprint and the center of the teres major footprint was 15.7 mm (Table 3), and the shortest distance between the 2 footprints was 4.4 mm. The distance from the center of the latissimus dorsi footprint to the center of the lesser tuberosity was 47.5 mm (Table 3), whereas the distance between the perimeters of each was 17.3 mm.

Table 4. Shortest Distances Between Perimeter of Bony Landmarks of Humerus and Perimeter of Humeral Tendon Attachments of Deltoid, Pectoralis Major, Latissimus Dorsi, and Teres Major Tendons, as well as Distances Between Center Points of Tendinous Attachments

	Distance to Perimeter of Humeral Deltoid, mm			Distance to Perimeter of Pectoralis Major, mm			Distance to Perimeter of Latissimus Dorsi, mm			Distance to Perimeter of Teres Major, mm		
		95% CI			95% CI			95% CI			95% CI	
	Mean	LB	UB	Mean	LB	UB	Mean	LB	UB	Mean	LB	UB
Distance from perimeter of lesser tuberosity	64.1	57.5	70.8	28.8	25.4	32.1	17.3	14.2	20.4	29.7	24.1	35.3
Distance from perimeter of greater tuberosity	57.0	49.9	64.1	23.4	20.4	26.5	19.9	17.4	22.5	31.8	27.7	35.9
Distance from perimeter of medial bicipital groove	21.8	13.1	30.5	3.5	2.5	4.6	0.6	0.2	1.0	6.2	4.1	8.4
Distance from perimeter of lateral bicipital groove	18.1	7.6	28.6	0.8	0.6	1.0	4.7	3.7	5.7	10.7	9.5	11.9
Distance from perimeter of humeral deltoid	—	—	—	3.4	1.2	5.5	18.2	12.3	24.0	14.7	12.0	17.5
Distance from perimeter of pectoralis major	—	—	—	—	—	—	3.9	2.7	5.1	9.5	8.3	10.8
Distance from perimeter of latissimus dorsi	—	—	—	—	—	—	—	—	—	4.4	1.9	6.9

CI, confidence interval; LB, lower bound; UB, upper bound.

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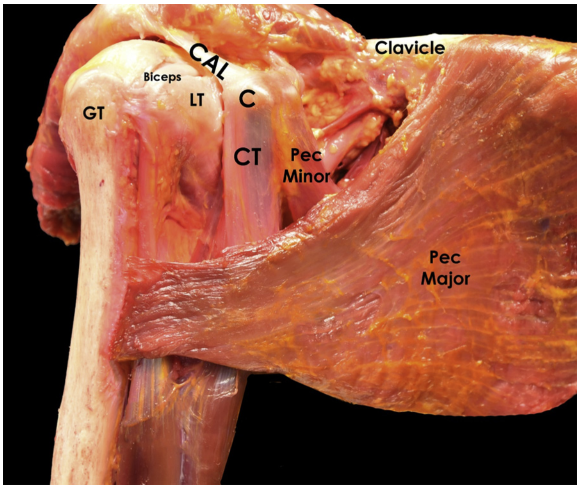

Fig 3. Anterior view of a right cadaveric shoulder showing the insertions of the pectoralis (Pec) major, conjoint tendon of the short head of the biceps and coracobrachialis (CT), and pectoralis (Pec) minor. The deltoid has been reflected to visualize the deeper structures. (C, coracoid; CAL, coracoacromial ligament; GT, greater tuberosity; LT, lesser tuberosity.)

Teres Major. With careful dissection, the latissimus dorsi and teres major tendons were always identified distinctly; however, in 2 of 10 specimens the proximal fibers of the teres major fused with the distal fibers of the latissimus dorsi 49.5 to 78.4 mm medial to the humeral insertion. The teres major tendon was of variable length, and its insertion on the humerus was generally broad and flat (Fig 4).

The teres major tendon inserted 6.2 mm and 10.7 mm medial to the medial and lateral borders of the bicipital groove, respectively. The insertion was 35.7 mm (95% CI, 32.1-39.3 mm) in length, parallel to the lateral border of the bicipital groove. The distance from the center of the teres major footprint to the center of the lesser tuberosity was 58.8 mm (Table 3), whereas the shortest distance between the lesser tuberosity and teres major was 29.7 mm.

Axillary Nerve. The anterior branch of the axillary nerve was identified in all specimens, coursing almost perpendicular to the axis of the humeral shaft, and localized within the deep fascia of the deltoid muscle (Fig 5). The greatest distance from the superior aspect of the greater tuberosity to the axillary nerve was 50.3 mm (95% CI, 47-53.5 mm). Furthermore, the shortest distance from the lateral acromion to the axillary nerve was 69.3 mm (95% CI, 64.1-74.5 mm). The distance from the center of the deltoid humeral attachment to the axillary nerve was 70.1 mm (95% CI, 64.6-75.7 mm), whereas the distance from the perimeter of the deltoid humeral attachment to the axillary nerve was 41.4 mm (95% CI, 36.1-46.8 mm). The distance of the axillary nerve from the tip of the greater tuberosity is highlighted because this distance will most likely not change with the position of the arm, unlike the distance between the axillary nerve and the acromion, which could change depending on the humeral position.

Discussion

The most important findings of this study were that consistent, quantifiable measurements and relations were obtained across specimens and can be used to guide surgeons in open procedures in the region of the proximal humerus in the neutral position. This quantitative anatomic information may be helpful for several shoulder-related procedures such as tendon transfers in cases of irreparable rotator cuff tears, arthroplasty for glenohumeral arthritis, and open reduction−internal fixation for proximal humeral fractures in which knowledge of the course of the axillary nerve may prevent iatrogenic injury. Moreover, 4 to 5 distinct deltoid tendinous bands were identified within the anterior and lateral aspects of the muscle, inserting on the anterior and lateral aspects of the acromion, which may correlate to the increased strength reported for this muscle in forward flexion and abduction as opposed to its strength limitations posteriorly.

The 2 heads of the pectoralis major muscle had distinct tendons that were continuous inferiorly starting from 33.3 to 43.7 mm medial to the humeral insertion and inserted lateral to the bicipital groove, which was comparable with a previous report.[24] In this study the pectoralis major insertion footprint was just lateral to the bicipital groove at an average of 0.8 mm from its lateral border. The latissimus dorsi always inserted lateral to the teres major footprint. Both tendons were flat and broad with footprints that were close together at a minimum distance of 4.4 mm. Similar to previous reports, in some specimens some of the teres major muscle fibers inserted on the latissimus dorsi tendon[25,26]; however, with careful sharp dissection, 2 separate tendon insertions were consistently identified. As noted in their assessment of 20 cadaveric specimens, Elhassan et al.[27] reported that the insertional anatomy of these 2 tendons was variable, including 11 with completely separate insertions, 7 with partially conjoined tendons, and 2 with a common tendon. The possibility of this variant should be noted when harvesting the latissimus dorsi tendon. Furthermore, it is important to understand and identify the proximity of the tendons' attachments on the humerus to avoid iatrogenic injury. Current tendon transfer procedures used for irreparable rotator cuff tears include the tendon of the sternal head of the pectoralis major,[28-30] latissimus dorsi,[10-12,31,32] and teres major tendons.[10,26,33]

In this study the distance from the superior aspect of the greater tuberosity to the axillary nerve was 50.3 mm. Furthermore, the distance from the lateral acromion to the axillary nerve was a mean of 69.3 mm.

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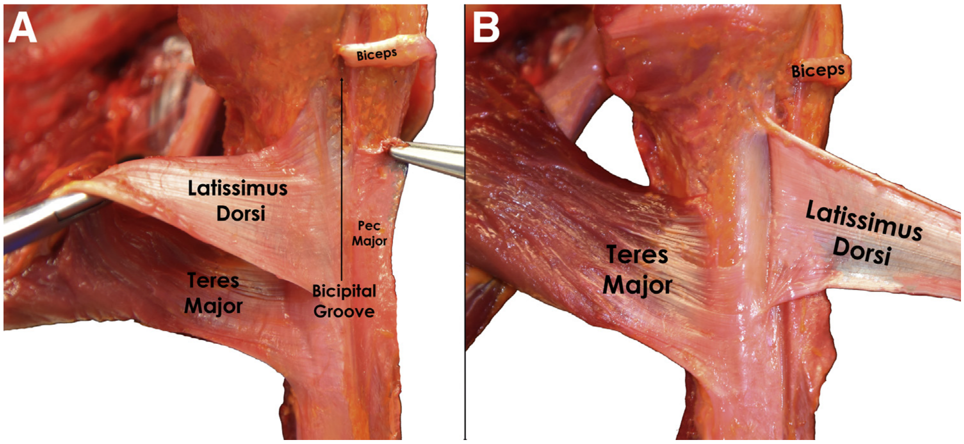

Fig 4. A dissected left cadaveric shoulder showing the relation between the pectoralis (Pec) major, bicipital groove, latissimus dorsi, and teres major tendons (A), with the latissimus dorsi tendon reflected laterally across the medial bicipital groove of the humerus (B) to show the separate tendon insertions of the latissimus dorsi and teres major. The long head of the biceps tendon was reflected proximally to better depict the bicipital groove.

These findings are comparable with previous studies that reported the distance to be 6.7 cm[34] to 6.8 cm.[35] Rates of injury to the axillary nerve during surgery range from 0% to 42% for the deltopectoral approach and 6% to 33% for the deltoid-splitting approach.[36] Previous studies have analyzed the anatomy of the axillary nerve, including 1 study by Burkhead et al.,[37] who reported that the classic teaching of "5 cm" was not an absolute safe zone for surgical dissection from the acromion because 20% of their cadaveric specimens contained an axillary nerve that was located less than 5 cm from the acromion at some point throughout its course. On the basis of the measurements obtained in this analysis, the incision and dissection in a deltoid-splitting approach should not exceed 47 mm from the tip of the greater tuberosity or 64.1 mm from the lateral acromion to avoid injury to the axillary nerve. Alternatively, if an incision must extend this far distally, care should be taken to identify and protect the axillary nerve, which was consistently identified in this location. Furthermore, performing an incision midway between the anterolateral and posterolateral corners of the acromion increases the risk of injury to 1 of the deltoid tendons. Understanding this anatomy is critical irrespective of the open shoulder surgical procedure being performed but is especially relevant when performing an approach that requires a deltoid split through the linear, tendinous portions of the deltoid.

Some measurements, such as the distance of the axillary nerve from the acromion, are clearly dependent on humeral position and therefore would change if studied in a position other than the neutral position. On

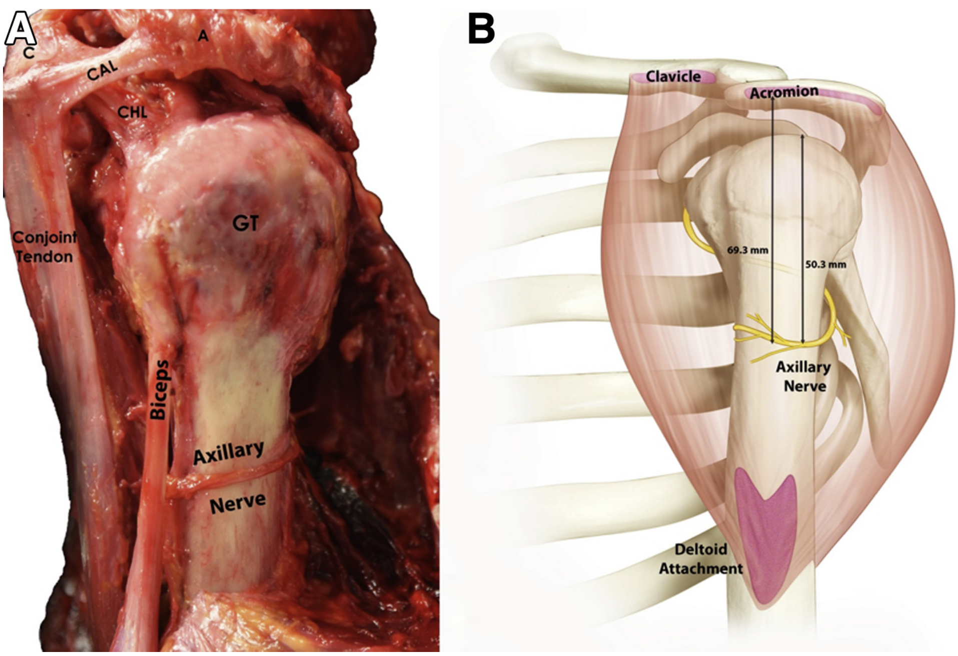

Fig 5. (A) A finely dissected left cadaveric shoulder with the axillary nerve course identified in relation with other anatomic landmarks. (A, acromion; C, coracoid; CAL, coracoacromial ligament; CHL, coracohumeral ligament; GT, greater tuberosity.) (B) Deltoid muscle and anterior branch of the axillary nerve. The axillary nerve is at risk of injury during open shoulder procedures.

the other hand, other data calculated, such as the distance between the nerve and the tip of the greater tuberosity, would not be expected to be a function of humeral position. In addition, measurements of structures on the humerus relative to other structures on the humerus and measurements intrinsic to the acromion would be constant despite humeral position. Although the course of the tendons from the insertions will change with a change in shoulder position, the insertion footprints of the tendons on the humerus relative to osseous landmarks on the humerus would not change, a point that we believe to be a strength of this study.

Limitations

This study is subject to the limitations inherent to cadaveric studies. Although a detailed dissection was performed to clearly visualize the anatomic attachments and fiber orientations, distances were calculated as absolute 3-dimensional vector norms, which do not provide directional information. Moreover, donor height and weight for the specimens used in this study were not available, and this could introduce potential bias. In addition, the relatively limited number of specimens may have led to underpowered results for the general population; however, the consistency and low standard deviations constitute a major strength of this report. Finally, the location of the axillary nerve was only quantified with the shoulder in a neutral position; thus its location in relation to other landmarks may change in other shoulder positions.

Conclusions

The deltoid muscle had 4 to 5 tendinous insertions on the acromion, and the axillary nerve was 50.3 mm from the tip of the greater tuberosity. The distance between the lower border of the pectoralis major and the axillary nerve was 9.4 mm.

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