Original Article

Neurovascular Anatomic Locations and Surgical Safe Zones When Approaching the Posterior Glenoid and Scapula: A Quantitative and Qualitative Cadaveric Anatomy Study

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Purpose: To characterize the qualitative anatomy of posterior scapula structures encountered with the Judet approach and to perform a quantitative evaluation of these structures' anatomic locations, including their relationships to osseus landmarks to identify safe zones. **Methods:** Twelve fresh-frozen cadaveric shoulders (mean age, 55.2 years; range 41-64 years; 5 left, 7 right) were dissected. A coordinate measuring machine was used to collect the coordinates of anatomic landmarks, structures at risk during surgical approach to the posterior scapula, and the footprints of muscle attachments on the posterior scapula. These coordinates were analyzed for their relationships with clinically relevant anatomy. **Results:** The suprascapular nerve was a mean of 20.3 mm (18.9-21.7 mm) medial to the glenoid 9-o'clock position. The posterior circumflex artery and vein were a mean of 100.0 mm (92.2-107.7 mm) lateral to along the lateral border of the scapula from the inferior angle of the scapula and a mean of 41 mm (34.2-47.9 mm) medial along the lateral scapular border from the 6-o'clock position on the glenoid rim. The long head of the triceps covers a mean of 132 mm^2, and it was found to be contiguous with the glenoid capsule at the 6-o'clock position. **Conclusions:** A safe zone exists 19 mm medially from the glenoid 9-o'clock position to the suprascapular nerve and a minimum of 34.2 mm medially along the lateral scapular border from the glenoid 6 o'clock to the posterior circumflex scapular artery. **Clinical Relevance:** The modified Judet approach is a minimally invasive surgery that reduces surgical trauma but necessitates precise knowledge of scapular neurovascular anatomy. Surgeons should be aware of these intervals to help avoid these structures when working near the posterior shoulder. This study may allow us to define neurovascular safe zones when this approach is used.

Extra-articular scapula fractures are relatively uncommon and have historically been treated nonoperatively with acceptable outcomes.[1,2] However, a lack of consensus exists, and there has been evidence of reduced shoulder function, arthrosis, rotator cuff dysfunction, and dyskinesia when these injuries are treated nonoperatively, with favorable outcomes from operative treatment.[3-5] With 90% of scapular fractures

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involving the body and neck of the scapula,[4,6] operative management has been of interest in recent years.

Indications for operative treatment include intra-articular fractures with a gap or step-off of greater than or equal to 4 mm, glenoid involvement greater than 25%, medialization of greater than 20 mm, glenopolar angle less than 22°, and angulation greater than 45°.[7] The Judet approach is the most commonly used operative approach for surgical repair of displaced scapula fractures. This approach provides excellent access for plate fixation of complex scapular fractures that involve lateral and medial scapular borders. The Judet approach has several modifications, but the original approach was described by Judet in 1964.[8] The majority of these fractures are high energy in nature and involve concomitant injuries that can lead to a delay in fixation.[1,7] With the location and size of the fracture and possible callus formation, it is important to note the neurovascular structures at risk during this approach. Special attention must be paid to the suprascapular nerve.[9] In addition, the posterior scapular circumflex artery courses around the lateral border of the scapula. Qualitative analysis of the posterior scapula and related anatomy have been conducted in the past[10]; however, quantitively defining distinct safe intervals would be of use. The purposes of this study were to characterize the qualitative anatomy of posterior scapula structures encountered with the Judet approach and to perform a quantitative evaluation of these structure's anatomic locations, including their relationships to osseus landmarks to identify safe zones. The hypothesis of this study was that repeatable safe zones would exist where these structures are not encountered using the anatomic locations of these structures and their relationships to easily identifiable landmarks.

Methods

Specimen Preparation

Twelve nonpaired, male fresh-frozen human cadaveric shoulders with no previous shoulder injury, history of bone metastasis, previous surgical history, or gross anatomic abnormalities that were younger than the age of 65 at death (mean age, 55.2 years; range 41-64 years; 5 left, 7 right) were used in this anatomic study. The specimens used in this study were donated to a tissue bank for medical research and then purchased by our institution using institutional funds. Cadaveric anatomy studies do not require institutional review board approval at our institution. All specimens were stored at −20°C and thawed at room temperature for 24 hours before preparation. During the course of dissection, specimens were kept hydrated with normal saline.

First, all skin and subcutaneous tissue was removed. All anterior and superficial musculature was then removed, taking care to leave the infraspinatus, teres minor, teres major, and the long head of the triceps intact, as well as the suprascapular nerve and the scapular circumflex neurovascular bundle intact and in their original, anatomical positions. During dissection, muscles were carefully retracted, and various areas were marked with a surgical marker onto the scapula. The points recorded included the footprints of the scapular insertion of the teres minor, teres major, and the triceps long head, as well as the point where the scapular circumflex neurovascular bundle crossed the medial border of the scapula and the point where the suprascapular nerve crossed the spinoglenoid notch closest to the glenoid. Once all necessary points were recorded with a surgical marker, all soft tissue was removed and the humerus was disarticulated.

Data Collection

The scapula was rigidly fixed to 2 custom shoulder clamps to minimize movement during data collection. A coordinate measuring machine (Romer absolute arm; Hexagon Metrology, Tucson, AZ) was used to collect the coordinates of anatomic landmarks and the footprints of muscle attachments on the posterior scapula. Collected landmarks included the inferior angle, most medial and lateral points of the teres major attachment, most medial and lateral points of the teres minor attachment, 9-o'clock position of the glenoid face, the point where the scapular circumflex vascular bundle crossed the medial border of the spine, the point where the suprascapular nerve crossed the spinoglenoid notch, and the most anterior, medial, lateral and posterior points of the triceps attachment. Collected footprint areas included teres minor, teres major, and triceps.

Data Analysis

The coordinates of the collected points were imported into MATLAB (MathWorks, Natick, MA) for analysis. Footprint areas were determined by calculating a best fit plane for each set of points, projecting those points onto the plane, and calculating the area of the resulting 2-dimensional polygon. Distance between landmarks were calculated as a direct linear distance between 2 collected points. All distances were expressed in millimeters, and all areas were expressed in mm^2.

Results

All measurements were reported as means with confidence intervals (Tables 1 and 2). In all specimens, the minimal distance from the glenoid rim to the suprascapular was at the glenoid 9-óclock position. The suprascapular nerve was found to course around the spinoglenoid notch and run inferior to the scapular spine as it interdigitates at its final innervation sites. With 95% confidence, the suprascapular nerve was located 18.9-21.7 mm medially to the glenoid 9-o'clock

Table 1. Distance Measurements Between Landmarks on the Posterior Scapula

Measurement	Mean Distance, mm	95% Confidence Interval Low	95% Confidence Interval High
Inferior angle of scapula to vascular bundle	100.0	92.2	107.7
Inferior angle of scapula to medial point of teres major	11.1	8.8	13.4
Inferior angle of scapula to lateral point of teres major	55.2	49.9	60.4
Inferior angle of scapula to medial point of teres minor	58.5	48.0	69.0
Inferior angle of scapula to lateral point of teres minor	116.4	104.1	128.7
Inferior angle of scapula to medial point of triceps	119.8	114.5	125.1
Inferior angle of scapula to lateral point of triceps	139.0	133.0	145.1
Medial point of teres major to vascular bundle	93.8	86.0	101.5
Lateral point of teres major to vascular bundle	47.4	38.3	56.4
Medial point of teres minor to vascular bundle	46.1	37.7	54.5
Lateral point of teres minor to vascular bundle	24.7	17.2	32.1
Medial point of triceps to vascular bundle	21.1	13.0	29.2
Medial point of teres major to lateral point of teres major	50.1	44.5	55.6
Medial point of teres minor to lateral point of teres minor	68.7	61.6	75.7
Medial point of triceps to lateral point of triceps	24.2	22.1	26.2
Anterior point of triceps to posterior point of triceps	12.5	11.0	14.1
Anterior point of triceps to medial point of triceps	22.8	19.3	26.2
Posterior point of triceps to medial point of triceps	22.9	19.1	26.7
Glenoid 9 o'clock to suprascapular nerve	20.3	18.9	21.7
Glenoid 6 o'clock to scapular artery	41.1	34.2	47.9

position (Fig 1). At the level of the glenoid 6-o'clock position, the lower bound of the 95% confidence interval for the distance from the glenoid rim to the posterior circumflex scapular artery and vein medially along the lateral border of the scapula was 34.2 mm, and the distance from the inferior angle of the scapula to the circumflex scapular vessels was a mean of 10 cm.

Long Head of Triceps

The long head of the triceps was found to be contiguous with the glenoid capsule at the 6-o'clock position and attached with triangular-shaped footprint on the lateral scapula inferior to the glenoid. Starting from the glenoid capsule, the footprint extended medially along the lateral border of the scapula (Fig 2). The footprint is widest at its most lateral attachment near the glenoid. The posterior scapular circumflex artery was found to be consistently located medially from the most medial edge of the triceps footprint.

Teres Minor

With careful dissection, it was possible to find distinct margins differentiating the teres minor and major footprints in all specimens. The teres minor was found to attach to the inferior most portion of the posterior side of the medial scapular border, starting at its widest point medially contiguous to the teres major footprint and becoming increasingly thin as it runs laterally ending in a thin footprint that overlaps posterior to the triceps insertion. The posterior circumflex scapular vasculature was found deep to the teres minor coursing inferior to the teres minor into the triangular space and continuing superficial to the teres major. There was a mean distance of 46.1 mm from the medial border of the teres minor to the posterior circumflex scapular artery and vein when traveling laterally along the lateral scapular boarder.

Teres Major

The teres major was found to have a broad attachment on the posterior surface of the inferior scapula. The footprint is thick throughout, with a medial to lateral distance of a mean 50.1 mm. The lateral border of the teres major is contiguous with the medial border of the teres minor, and the muscle runs anteriorly to the long head of the triceps. The posterior circumflex artery and vein run superficially to the teres major laterally to the lateral border of the teres major along the lateral boarder of the scapula.

Discussion

The principle finding of this study was that measurements and anatomical relations on the posterior aspect of the scapula were consistent and quantifiable. A safe zone could be defined on the posterior aspect of the glenoid in regard to the suprascapular nerve. Moreover, the posterior scapular artery was identified at the lateral border of the scapula. These reliable measurements would be important to surgeons when

Table 2. Area Measurements of Muscle Attachment Footprints on the Posterior Scapula

Row	Average, mm2	95% Confidence Interval Low	95% Confidence Interval High
Area of teres major	787.1	670.2	904.0
Area of triceps	132.4	115.2	149.5
Area of teres minor	574.1	469.3	678.9

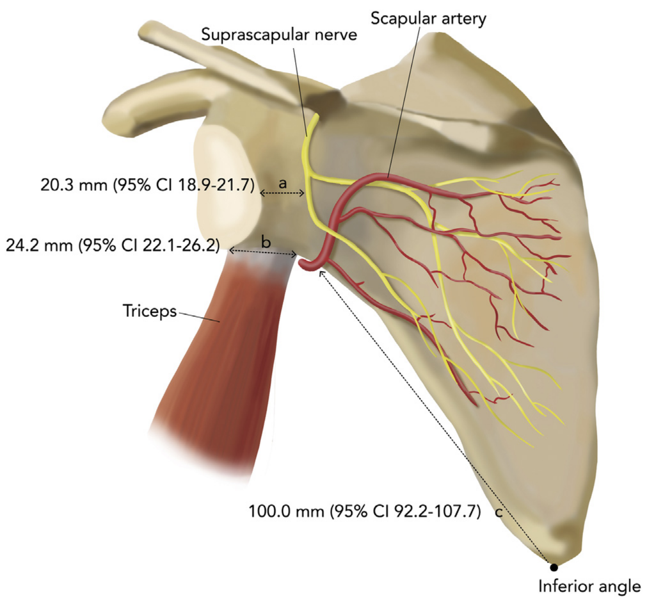

Fig 1. Relative locations of the suprascapular nerve, posterior circumflex scapular artery, and the long head of the triceps muscle and quantitative mean distances with 95% confidence intervals (CI) are shown. Distance "a" represents a mean distance from the glenoid 9 o'clock position to the suprascapular nerve as it passes around the spinoglenoid notch closest to the glenoid with a mean of 20.3 mm and a minimum safe distance of 18.9 mm. Distance "b" represents the medal to lateral length of the triceps insertion with a mean of 24.2 mm. Distance "c" represents the distance from the inferior angle of the scapula to the posterior circumflex scapular artery and vein with a mean of 100.0 mm.

performing both arthroscopic and open shoulder surgery. The minimal distance from the glenoid rim to the suprascapular nerve was consistently identified at the 9-o'clock position. The lower bound of the 95% confidence interval was 18.9 mm from the glenoid rim. This knowledge can help surgeons in safe positioning of anchors and screws on the posterior aspect of the glenoid. Knowledge of the location of the vascular bundle in relation to the inferior angle of the scapula can be helpful to avoid vascular damage in open reduction and internal fixation of scapular fractures. The Judet approach is extensive but can also be performed with less-extensive windows. However, knowledge of the location of the neurovascular structures is paramount. The vascular bundle could be quantified consistently with a mean distance of 10 cm from the inferior angle. This knowledge can aid surgeons to protect the vascular bundle or ligate the vessels, thus reducing the risk of hemorrhage and hematoma. Given the extensive nature of Judet approach with mobilization of the infraspinatus muscle from medial to lateral, reduced risk of hematoma would be important.

Posterior glenoid fractures require the use of less-practiced and more complex surgical approaches. While attempting these approaches, it is important to be cognizant of the relationships that exist between important structures when placing screws or plates. Anterior glenoid fractures and fractures that involve the base of coracoid process also require care to be taken regarding screw placement in respect to the location of the suprascapular nerve on the posterior surface of the scapula in the spinoglenoid notch. As for arthroscopic procedures, studies have shown that placement and trajectory of anchors can result in injury to the suprascapular nerve.[11,12] In the present study, the suprascapular nerve was found to be flush with the spinoglenoid notch with the smallest safe distance of 18.9 mm to the 9-o'clock position on the posterior glenoid rim. When repairing anterior glenoid fractures,[13] or during the Latarjet procedure, the surgeon should be careful that bicortical screws remain within 18 mm from the 9-o'clock position on the glenoid when exiting the posterior cortex in order to protect against damage to the nerve. With the nerve found in this study to be flush to the posterior cortex, a drill or screw driven toward the spinoglenoid notch could result in neuritis or irritation to the nerve that should be avoidable by staying within the noted safe distance from the glenoid rim.

Concomitant arterial injury can occur with the scapular fracture or inadvertently during surgical exposure. The descending branch of the circumflex scapular artery runs together with the suprascapular nerve. Thus, the ascending branch can be ligated if damaged or out of necessity to provide extended access along the along

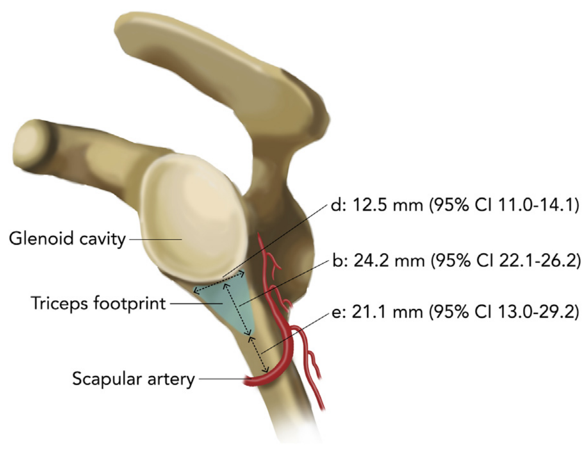

Fig 2. Lateral view of the scapula showing the relation of the triceps footprint to the glenoid and the posterior circumflex scapular artery with distance "b" being the medial to lateral thickness of the triceps muscle insertion with a mean of 24.2 mm. Distance "d" is the anterior posterior thickness of the triceps muscle footprint at its thickest point contiguous with the glenoid capsule with a mean thickness of 12.5 mm. Distance "e" is the mean distance of 21.1 mm between the most medial point of the triceps footprint to the posterior circumflex scapular artery. (CI, confidence interval.)

the lateral scapular border.[14] However, bleeding from the ascending branch of the circumflex scapular artery can be profuse and result in extensive hematoma.

The modified Judet approach uses the intermuscular plane between the infraspinatus and teres minor muscle to access the lateral scapular border and complete dissection of the infraspinatus muscle from the scapula is not necessary. However, the ascending branch of the circumflex scapular artery is encountered during this approach and is at risk for iatrogenic injury. In the present study, the ascending branch of the scapular artery crossed the lateral scapular border 10 cm from the inferior angle. The distance from the 6-o'clock glenoid position and medial border of the triceps tendon insertion on the scapula to the anterior branch of the scapular artery was 41.1 mm and 21.1 mm, respectively. The inferior angle of the scapula is easily palpable through the skin and after elevation of the subcutaneous flap. Thus, the distance from the inferior angle to the point where the artery crosses the lateral border has practical benefit during surgery, especially when using minimally invasive surgical approaches.

The triceps muscle consists of 3 heads—the medial, lateral, and long heads. In contrast to the lateral and medial heads, the origin of the long head is on the scapula. Thus, the function of the long head is not excluded to elbow extension. In adduction, the long head contributes to dynamic stabilization of the glenohumeral joint and in extension and adduction of the shoulder joint. Scapular fractures involving the neck and/or glenoid require partial detachment of the long head of the triceps tendon footprint on the infraglenoid tubercle to accommodate fracture reduction and plate fixation. In the present study, the footprint was triangularly shaped and the distance from the 6-o'clock position to the apex was 24.2 mm. This information can be helpful when deciding how much of the triceps tendon can be detached without risking complete detachment of the long head of the triceps muscle.

Limitations

We acknowledge there are limitations inherent in a cadaveric model that are not fully representative of the in vivo state. ROMER measurements provide a 2-dimensional distance between structures, which may not directly relate to intraoperative 3-dimensional measurements. This may lead to an over or underestimate of the distance between related structures in this study. The specimens used in this study had no previous injury, so distances may vary depending on location and displacement of fractures in the clinical setting. Additionally, the scope of this study is narrow, and further studies are needed to quantify distances and trajectories to structures of interest encountered during other approaches to the scapula and in arthroscopic procedures.

Conclusions

A safe zone exists 19 mm medially from the glenoid 9-o'clock position to the suprascapular nerve and a minimum of 34.2 mm medially along the lateral scapular border from the glenoid 6 o'clock to the posterior circumflex scapular artery.

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