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Characterization of an anatomic safe zone surrounding the lower subscapular nerve during an open deltopectoral approach

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Background: Due to anatomic variance in subscapular nerve innervation patterns, it is theorized that the dysfunction of the subscapularis could be the result of iatrogenic denervation during mobilization of the subscapularis while exposing the anterior glenohumeral joint in anterior surgical approaches. The purpose of this study was to describe innervation patterns of the subscapularis and to characterize a safe zone when conducting an anterior surgical approach.

Methods: The study used 6 human cadaveric shoulder specimens (12 shoulders total). A deltopectoral approach was used to expose the axillary nerve back to the posterior cord of the brachial plexus and reveal the origins of the upper and lower subscapularis nerves. An anatomic safe zone was characterized by measuring distances from both the upper and lower subscapularis nerve insertions with respect to that of the lateral border of the conjoint tendon, the bicipital groove, superior border of the subscapularis, and the axillary nerve (for the lower subscapular nerve only) with the arm in 30° abduction.

Results: The anatomic safe zone of the subscapular nerves medial to the conjoint tendon is less than 32 mm. In relation to the axillary nerve, the safe zone is less than 10 mm inferiorly and 15 mm medially.

Conclusions: This described safe zone with respect to the lateral border of the conjoint tendon and axillary nerve is aimed to provide guidance to reduce iatrogenic injury of the subscapular nerves during anterior shoulder exposure. Extra care should be undertaken while dissecting past this safe zone to prevent iatrogenic subscapular nerve injury.

Level of evidence: Anatomy Study; Cadaveric Dissection

Keywords: Subscapular nerve; deltopectoral approach; shoulder arthroplasty; cadaveric; iatrogenic nerve injury; prevention; anatomic safe zone; surgical exposure

The deltopectoral approach is the most common surgical approach to the shoulder for procedures such as shoulder arthroplasty, open instability repair, and fracture fixation.[9,21,31] Glenohumeral joint exposure often requires mobilization of the subscapularis, and postoperative subscapularis dysfunction remains a concern.[20,25] This may be related to poor healing of the subscapularis repair, failure of the repair, or

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iatrogenic injury to the subscapular nerves.[6,8,18,20,24,26] Several techniques have been described to address the subscapularis tendon to access the glenohumeral joint.[23,27]

With regard to total shoulder arthroplasty, debate exists regarding the best technique for detachment and repair of the subscapularis tendon.[27] These techniques include subscapularis tendon tenotomy, peel of the subscapularis tendon from the lesser tuberosity, lesser tuberosity osteotomy, and subscapularis-sparing alternatives. Despite the theorized benefit of subscapularis-sparing approaches, this exposure is considered technically challenging, may precipitate implant malplacement, and lacks conclusive biomechanical and clinical data to routinely support its use.[23,27] This has prompted surgeons away from subscapular-sparing techniques, favoring glenohumeral joint exposure through subscapularis tenotomy, peel, or lesser tuberosity osteotomy.

Subscapular dysfunction has been shown to lead to instability of the glenohumeral joint and poor shoulder function.[10,15,29] Iatrogenic nerve injury risks may be increased due to the lack of surgeon appreciation of the proximity of the subscapular nerves in addition to the anatomic variance in subscapular nerve morphology and innervation.[1] Comprehensive descriptions of the anatomic variation in subscapular nerve branches are lacking. Anatomists have historically identified the innervation to the subscapularis muscle as the upper and lower subscapular nerves, both originating from the posterior cord and bisected by the thoracodorsal nerve. Few studies, however, have described the significant variability in their patterns.[13,14,33] The upper and lower subscapular nerves predominately originate from the posterior cord, receiving fibers from C5 and C6, respectively; however, the upper subscapular nerve frequently originates as more than 1 branch.[12] Some have theorized that the lower subscapular nerve may show greater variability in its innervation with contributing branches arising from the posterior cord, axillary nerve, or thoracodorsal nerve.[13,14,33] The axillary nerve parallels the inferior border of the subscapularis as it travels toward the quadrilateral space.

Some reports have examined the subscapular nerve and adjacent anatomic landmarks to provide surgical guidance to avoid subscapular nerve injury; however, these recommendations are limited in their utility because they describe anatomic references that may not be apparent during the surgical exposure with a deltopectoral approach.[4,5,12,16,33] Kasper et al,[12] for example, report the location of the subscapular nerves relative to the base of the coracoid near the anterior rim of the glenoid at the level of the joint internally. By the time the surgeon gets to these intra-articular anatomic structures, the damage to the subscapular nerves in the extra-articular environment may have already occurred.[12]

As such, there is a need for a more detailed description of the subscapular nerve anatomy relative to the anatomic structures that are encountered during surgical exposure through a deltopectoral approach external to the glenohumeral joint. The purpose of this study was to describe innervation patterns of the subscapularis muscle and identify reproducible and surgically relevant anatomic landmarks to the subscapular nerves. This is to provide guidance for a safe zone to reduce risk of iatrogenic injury to the subscapular nerves during anterior shoulder exposure.

Materials and methods

The study used 6 human cadaveric shoulder specimens. The right and left shoulders were both used from each cadaver (12 total). All shoulders were normal for glenohumeral anatomy and other structures involving the anatomic area of interest, including the rotator cuff muscles, supplied by the posterior cord of the brachial plexus (teres major, subscapularis, latissimus dorsi). Other structures adjacent to our experimental measurement zone (pectoralis major, serratus anterior, conjoint tendon, biceps tendon, latissimus dorsi) were evaluated and deemed void of any pathology.

Dissection technique

Dissections were performed by a single anatomist (HL) and 1 of 2 orthopedic surgeons (AA, GU). A deltopectoral approach was used, as previously described.[12,16] The deltoid was mobilized laterally. The pectoralis major was mobilized medially and then released from its insertion on the humerus to further expose the deeper pectoralis minor. The pectoralis minor was cut at the level of the coracoid and reflected medially to expose the subscapularis and the brachial plexus.

The axillary vein and artery were ligated and tied off to prevent excess blood in the field. The axillary nerve was identified at the inferior border of the subscapularis muscle and traced back to the posterior cord of the brachial plexus. The origins of the upper and lower subscapularis nerves were identified by first locating the thoracodorsal nerve and then tracking proximally to identify the subscapular nerve. Any additional contributing innervating branches and variations of the subscapular nerve were documented. To the best of the ability of the dissector, all brachial plexus nerves were left adhered to their muscular or fascial attachments to avoid disturbing native morphology.

Description of measurements

After completion of the dissection and exposure of the subscapular nerves with the surrounding brachial plexus, the insertion points of the upper and lower subscapular nerves were marked with a pin (Fig. 1). The humerus was placed in neutral rotation and 30° abduction. The lateral border of the conjoint tendon (with clavipectoral fascia released to better identify the lateral border), the axillary nerve, and the bicipital groove were also identified and marked with a pin (Fig. 1). The rotator interval was opened, and the superior border of the subscapularis was identified. Horizontal distances from the upper and lower subscapularis nerve insertions were measured (mm) orthogonal to that of the lateral border of the conjoint tendon and the bicipital groove with the arm in neutral rotation at 30° abduction. Vertical distances (mm) from the upper and lower subscapular nerve insertions with respect to the superior border of the subscapularis were measured. Vertical and horizontal distances from the branch point of the axillary nerve on the

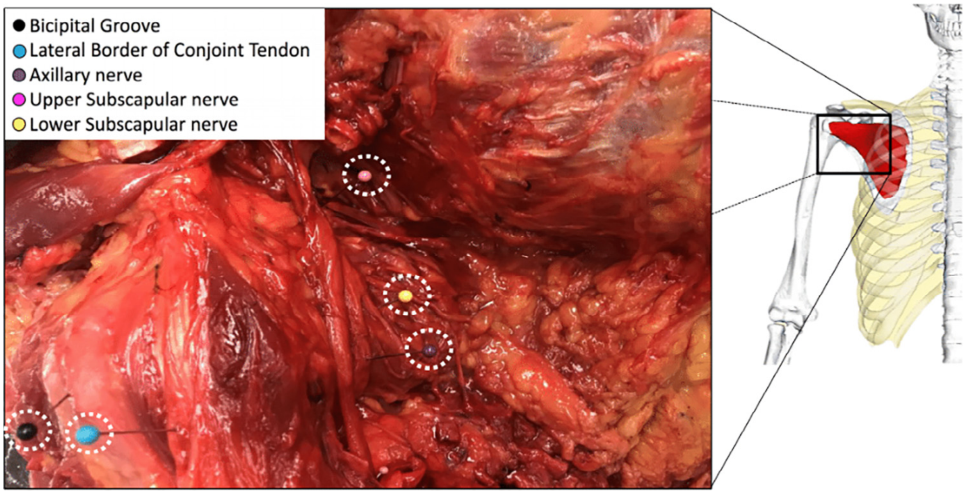

Figure 1 Exposure of the subscapular nerves with the surrounding brachial plexus: the insertion points of the upper and lower subscapular nerves were marked with a pin after completion of the dissection (as shown). The humerus was placed in neutral rotation and 30° abduction. The lateral border of the conjoint tendon (with clavipectoral fascia released to better identify the lateral border), the axillary nerve, and the bicipital groove were also identified and marked with a pin (as shown). The rotator interval was opened, and the superior border of the subscapularis was identified.

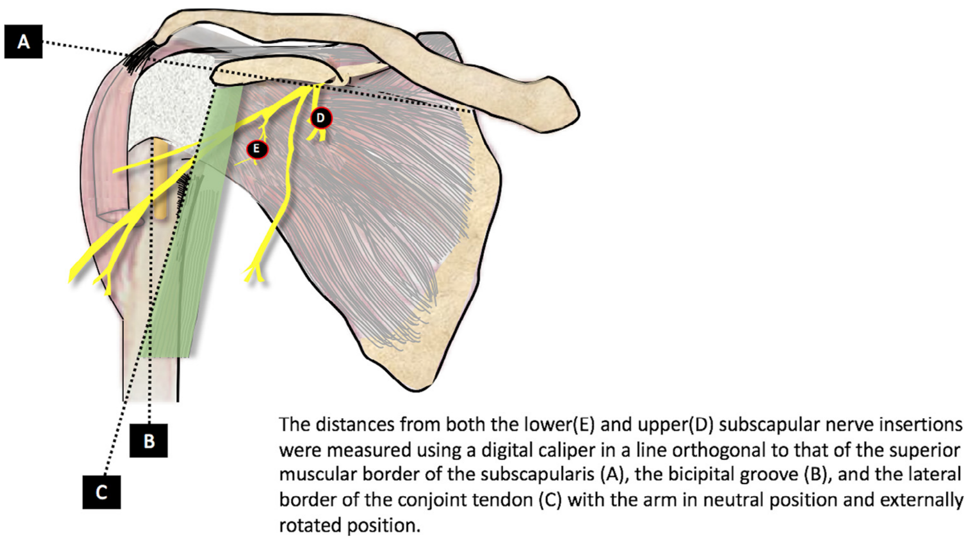

Figure 2 Illustration of measurements. The distances from both the lower (*E*) and upper (*D*) subscapular nerve insertions were measured using a digital caliper in a line orthogonal to that of the superior muscular border of the subscapularis (*A*), the bicipital groove (*B*), and the lateral border of the conjoint tendon (*C*) with the arm in neutral rotation and 30° abduction.

posterior cord were only measured with respect to the insertion of the lower subscapular muscle nerve. Distances were not measured from the axillary nerve to the upper subscapular nerve because only the lower subscapular nerves were considered most vulnerable to denervation during localization of the axillary nerve at the deltopectoral interval and of interest in this anatomic investigation. Figure 2 illustrates the described measurements. All measurements were taken using a digital caliper with a straight edge to guide accurate measurements. Mean, standard deviations, and ranges of measurements (minimum [min] and maximum [max]) were calculated and are described in Table I and Table II. The procedure was repeated and photographed for each specimen.

Table I Descriptive results of donor specimens with unique subscapular innervation

Donor	Description
Donor 3, left shoulder	Two upper subscapular branches
Donor 1, left shoulder	Thin auxiliary contributing branch from base of lower subscapular nerve
Donors with unique branching patterns, No (%)	2/12 (16.7)

Table II Mean distance from the insertion point of the upper subscapular nerve branch to the lateral conjoint tendon, superior border of the subscapularis, and bicipital groove

Structure	Neutral position in 30° abduction					
	Horizontal distance from lateral border of conjoint tendon (mm)		Vertical distance from superior border of the subscapularis (mm)		Horizontal distance from bicipital groove (mm)	
	Mean ± SD	Min-Max	Mean ± SD	Min-Max	Mean ± SD	Min-Max
Upper subscapular nerve branch	52 ± 9	40-73	16 ± 4	7-21	73 ± 11	60-83

SD, standard deviation; *Min*, minimum; *Max*, maximum.

Results

Demographics

The 6 cadaveric donor specimens (3 men and 3 women) were an average height of 172 cm (range 150-183 cm). Descriptive results of donors with unique subscapular innervations are reported in Table I.

Anatomic measurements

Mean distances from insertion point of the upper subscapular nerve to the lateral border of the conjoint tendon, superior border of subscapularis, and bicipital groove in neutral position of 30° abduction are reported in Table II. The distance from the superior border of the subscapularis to the upper subscapular nerves (line of A to point D on Fig. 2) averaged 16 ± 4 mm (min: 7 mm, max: 21 mm; Table II). The horizontal distance from the lateral border of the conjoint tendon and bicipital groove to the upper subscapular nerve (line of B to point D and line of C to point D in Fig. 2, respectively) were 73 ± 11 mm (min: 60 mm, max: 83 mm) and 52 ± 9 mm (min: 40 mm, max: 73 mm), respectively.

Mean distances from the insertion point of the lower subscapular nerve to the lateral border of the conjoint tendon, upper border of subscapularis, axillary nerve, and bicipital groove are reported in Table III. The average horizontal distance from the axillary nerve to the lower subscapular nerve was 14 ± 8 mm (min: 3 mm, max: 29 mm. The average vertical distance of the lower subscapular nerves to the axillary nerve was 11 ± 5 mm (min: 4 mm, max: 25 mm). The average vertical distance from superior border of the subscapularis and lower branch of subscapular nerve (line of A to point E on Fig. 2) was 40 ± 9 mm (min: 29 mm, max: 52 mm). The average horizontal distance of the lower subscapular nerve to the bicipital groove (line of B to point E on Fig. 2) was 64 ± 8 mm (min: 57 mm, max: 76 mm). The average horizontal distance of the lower subscapular nerve to the lateral border of the conjoint tendon (line of C to point E on Fig. 2) was 47 ± 8 mm (min: 32 mm, max: 57 mm).

Discussion

In this anatomic cadaveric study we observed the lower subscapular nerve branch innervated the subscapularis at a distance of less than 15 mm from the axillary nerve (Table III). Moreover, some specimens demonstrated measurements of subscapular nerve contributions as short as 3 mm from the axillary nerve. This underscores the theoretical risk of iatrogenic injury or denervation to the subscapularis during release and mobilization of the musculotendinous unit. It is not uncommon for surgeons to identify the axillary nerve with a finger sweep approach during a deltopectoral approach, which could put the subscapular nerves at risk if done heavy

Table III Mean distance from the insertion point of the lower subscapular nerve branch to the lateral conjoint tendon, superior border of the subscapularis axillary nerve, and bicipital groove

Structure	Neutral position in 30° abduction									
	Horizontal distance from lateral border of conjoint tendon (mm)		Vertical distance from superior border of the subscapularis (mm)		Horizontal distance from axillary nerve (mm)		Vertical distance from axillary nerve (mm)		Horizontal distance from bicipital groove (mm)	
	Mean ± SD	Min-Max	Mean ± SD	Min-Max	Mean ± SD	Min-Max	Mean ± SD	Min-Max	Mean ± SD	Min-Max
Lower subscapular nerve branch	47 ± 8	32-57	40 ± 9	29-52	14 ± 8	3-29	11 ± 5	4-25	64 ± 8	57-76

SD, standard deviation; *Min*, minimum; *Max*, maximum.

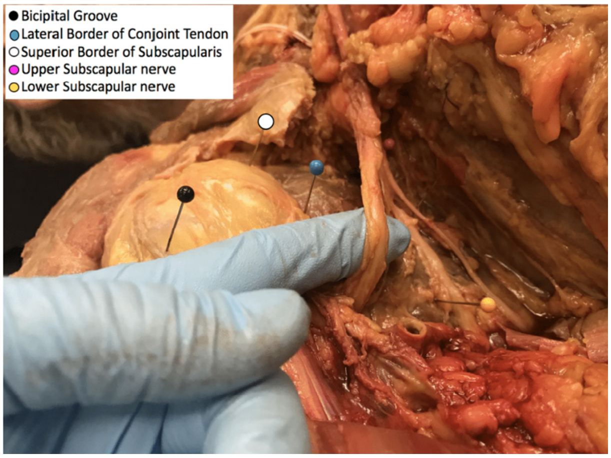

Figure 3 Illustration of risk of iatrogenic injury or denervation to the subscapularis during release and mobilization of the musculotendinous unit. Shown above is the finger sweep approach without visualization of the posterior cord. Shown below is the axillary nerve with a finger sweep approach during a deltopectoral approach, which could put the subscapular nerves at risk (tip of finger).

handedly (Fig. 3) In addition, anatomic variation, along with poor understanding of the anatomy by the shoulder surgeon, contributes to possible iatrogenic injury to the subscapular nerves, as mentioned above. Taken together, one may reasonably wonder from these findings whether contact with subscapular nerves is more common than what has been previously reported. As such, we caution against a heavy-handed sweep when palpating and recommend a gentle palpation when identifying the axillary nerve during a deltopectoral approach.

That neurologic dysfunction to the subscapularis may be a postoperative complication and potential cause of iatrogenic glenohumeral instability and dysfunction after anterior shoulder surgery has been previously reported.[2,6,8,12,13,20,24,26] In regards to total shoulder arthroplasty, Armstrong et al[1] reported that although the subscapularis muscle remains innervated and contractile at 1 year after surgery, the subscapularis shows evidence of chronic denervation and reinnervation in up to 30% of shoulders, with isolated involvement in 10% of shoulders through electromyography. This study provides anatomic data that may help reason why this neurologic dysfunction occurs. Anatomic variance in subscapular nerve morphology and its unique innervation patterns strengthens the theory that the dysfunction of the subscapularis could be the result of iatrogenic denervation during release and mobilization of the subscapularis while exposing the anterior glenohumeral joint.[1]

This further adds to the debate regarding the use of various techniques to address the subscapularis when exposing the anterior glenohumeral joint[11,17,19,28,30] and can provide useful perioperative guidelines to consider during techniques involving the deltopectoral surgical approach. Numerous biomechanical investigations have evaluated optimal management of subscapularis tendon during total shoulder arthroplasty.[22,23,31] In fact, a 2017 review by Shields et al[27] aimed to reveal optimal management of the subscapularis tendon during total shoulder arthroplasty; however, they were unable to recommend a specific technique due to inconsistencies, largely equivalent albeit satisfactory findings, and limited Level 1 evidence in the current literature.[27] In addition, Sacevich et al comments on the limitations of biomechanical studies to date, which vary significantly in regard to the quality of cadaveric tendon and bone, osteotomy size, type and size of suture material, use and type of cemented or uncemented prostheses, inclusion of buttress plate augments, encircling of the prosthesis with suture material, and testing protocols.[7,22,23,32] Taken together, there is a paucity of evidence in the current orthopedic literature that can be used to guide operative techniques in anterior shoulder operations to prevent subscapularis dysfunction.

In a recent cadaveric study, Leschinger et al[16] challenged the safety of these techniques and submitted that current approaches that aim to preserve lower subscapular muscle attachment may carry a significant risk of denervation to the lower and middle portions of the subscapularis muscle. These authors used the musculotendinous junction of the subscapularis and base of the coracoid process as anatomic landmarks in quantifying theoretical risk of subscapular denervation and reported that release should be avoided more than 1 cm medial to the musculotendinous junction on the anterior aspect of the subscapularis muscle. Their investigation helps to define a potential safe zone for avoiding denervation of the subscapularis during surgical exposure but does not provide practical intraoperative landmarks for surgeons to use during a deltopectoral approach or shoulder arthroplasty because the base of the coracoid is deep to the joint and is not visible during initial surgical approach and the musculotendinous junction is not often identified. Thus, although their findings are conceptually significant in characterizing the anatomic space surrounding subscapular nerve contributions, they are not specific enough to guide surgical technique.

During the deltopectoral approach, after the interval between the deltoid and pectoralis muscle has been mobilized, one of the first anatomic structures identified is the clavipectoral fascia, which overlies the subscapularis tendon. The clavipectoral fascia must be released to expose the subscapularis, and secondarily, this identifies the lateral extent of the conjoint tendon. The subscapularis nerves cannot be directly visualized because the conjoint tendon overlies their insertion sites. The average horizontal distance from the conjoint tendon to the upper subscapular nerve was 52 mm and to the lower subscapular nerve was 47 mm. This demonstrates that the lower subscapular nerve is closer to the field than the upper subscapular nerve in the horizontal plane when undermining the conjoint tendon. With respect to conservative measure distances, the safe zone to mobilize under the conjoint tendon for the lower subscapular nerve was less than 32 mm, with the average being 47 mm and some specimens showing distances as far as 57 mm.

The axillary nerve is often palpated when undermining the conjoint tendon, and a “tug test” has been described to

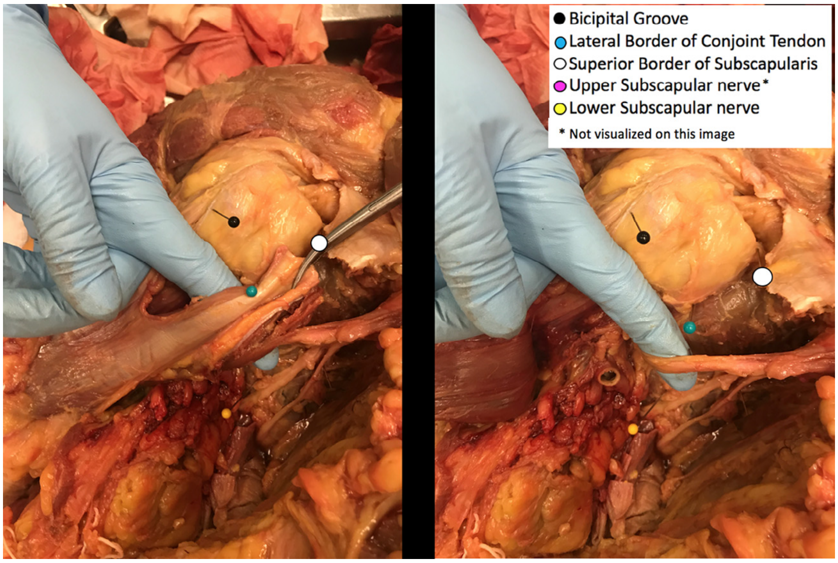

Figure 4 Demonstration of proximity of lower subscapular nerve during localization of the axillary nerve during a "tug test." In our cadaveric study, the lower subscapular nerve insertion site was located <15 mm medially from the axillary nerve in the horizontal plane and <11 mm inferiorly in the vertical plane.

localize the axillary nerve.[3] The lower subscapular nerve insertion site was located <15 mm medially from the axillary nerve in the horizontal plane and <11 mm inferiorly in the vertical plane (Fig. 4). This places the lower subscapular nerve at higher risk when localizing the axillary nerve. Although it is true that the upper subscapular nerve insertion was found to be marginally close in the horizontal plane to the axillary nerve, it is more protected because it is more proximal. However, when the rotator interval is released, then the upper subscapular nerve would be at risk if the release extends beyond 40 mm medial to the conjoint tendon. It is important to note, however, that release of the rotator interval, which ends at the superior rim of the glenoid, does not necessarily place the subscapular nerves at risk. What places the subscapular nerves at risk is tenotomy of the subscapularis tendon and medial release of the subscapularis muscle, particularly if it has been chronically retracted and needs release of scar tissue to mobilize.

This study also provides experiential evidence that anatomic variation exists between patients with respect to innervation of the subscapularis that confers a potential risk for iatrogenic injury to the subscapular nerves during shoulder procedures using a deltopectoral approach. These findings echo those previously described concerning variable patterns of innervation to the subscapularis, yet in most cases, the posterior trunk of the brachial plexus provided upper subscapular, lower subscapular, and thoracodorsal nerves, which is consistent with traditional anatomic teaching.[12,16,33]

This study is not without limitation. Primarily, this investigation is limited in its sample size of 12 cadaveric shoulders. Although higher-powered anatomic studies may further refine the theoretical safe zone from which iatrogenic injury to subscapular nerves is side stepped, this study provides meaningful data in understanding the relative proximity of vulnerable structures when localizing the axillary nerve. Furthermore, variability in pin placement and placement depth may have affected measurements.

With the acknowledgement of these limitations in this anatomic cadaveric study, we aim to offer some guidelines to surgeons using a deltopectoral approach that may aid in protecting the subscapular nerves.

Conclusions

This cadaveric study provides surgically relevant anatomic landmarks to better identify the location of the upper and lower subscapular nerves and decrease the risk of iatrogenic injury during a deltopectoral approach. We have described an anatomic safe zone for the lower subscapular nerve, which we feel is most at risk: less than 32 mm medial to the conjoint tendon during mobilization and less than 11 mm inferiorly and 15 mm medially to the axillary nerve (at the lower border of the subscapularis) during localization of the axillary nerve. Dissecting past this safe zone may put the lower subscapular nerve at risk of injury.

Disclaimer

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