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Surgical anatomy of the axillary nerve and its implication in the transdeltoid approaches to the shoulder

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Background: Traumatic and iatrogenic injuries of the axillary nerve (AN) are frequent in clinical practice; nevertheless, its anatomy and its relationships with the transdeltoid approaches to the shoulder are not well documented.
Materials and methods: Anatomic study was performed on 16 shoulders of unembalmed cadavers. A proximal humeral internal locking system (PHILOS) plate was placed to simulate the osteosynthesis of a fracture of humeral surgical neck. The relationships between the plate and the nerve were evaluated. Selective dissection of all the nerve branches inside the deltoid muscle was performed.
Results: The mean distance between the point where the AN entered into the deltoid muscle and the humeral head was 5.0 cm, and it was 6.8 cm from the acromion. The mean distance between the origins of the anterior and posterior branches of the axillary nerve was 5.4 cm. The mean diameter of the AN was 0.57 cm, the anterior branch diameter was 0.40 cm, of posterior branch diameter was 0.33 cm, and the teres minor branch diameter was 0.24 cm. The application of the PHILOS plate demonstrated that in 100% of cases, the 2 distal holes of the plate of those dedicated to the humeral head coincided with the passage of AN.
Discussion: The different patterns of nerve branches inside the deltoid muscle show that the ‘‘safe zone’’ during transdeltoid approaches is the anterior region of the deltoid muscle for a maximum of 6.7 cm from the acromion. In addition, the insertion of the 2 distal screws of those dedicated to humeral head of the plate should be avoided.
Level of evidence: Basic Science Anatomy Study.

Keywords: Axillary nerve; shoulder; deltoid; minimally invasive approach; plate osteosynthesis; orthopaedic surgery; nerve lesion

In recent years, orthopedic surgeons' interest in the axillary nerve, or circumflex nerve, has been growing because it can be damaged during shoulder arthroscopy,[11,14,19,30] thermal shrinkage of the shoulder capsule,[19,22] internal fixation of proximal humeral fractures,[6,12,27] and intramuscular

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injection at the deltoid muscle.[9] The axillary nerve is also the more common nerve to be injured after anterior dislocation of the shoulder[18] and in traumas of this region,[1,2] representing approximately the 42% of all brachial plexus injuries.[3] Lesion of the axillary nerve causes an atrophy of the deltoid muscle, an associated deficit of the abduction movement of the arm, and hypoesthesia of a small lateral area of the shoulder. The axillary nerve has also some branches for the shoulder joint capsule[10] and for the inferior glenohumeral ligament[15] that are determinant for the proprioception of the shoulder joint.

It is thus important for orthopedic surgeons to preserve the axillary nerve, but this could be difficult, especially when lateral[25,27] or anterolateral[23,29] minimally invasive approaches to the humerus are used.[4,7] Compared with the classical deltopectoral approach, the lateral and anterolateral deltoid-splitting approaches allow a limited surgical incision that respects the surrounding tissues, and thus a minor lesion, a more rapid rehabilitation, and a better aesthetic scar are possible.[17]

Nevertheless, it is impossible to directly see the axillary nerve, which increases the risk of a nerve lesion. In particular, Smith et al[27] described the relationships of this nerve with the 3.5-mm LCP Distal Humerus Plate (Synthes, West Chester, PA), showing that 3 holes in the middle of the plate were consistently intersected by the course of the axillary nerve; thus, they cannot be safely inserted in a lateral percutaneous approach. Even so, the surgical technique for proximal humeral internal locking system (PHILOS, Synthes, Stratec Medical Ltd, Mezzovico, Switzerland) plate fixation recommends a generic deltopectoral or transdeltoid approach. Gardner et al[13] have suggested using the anterolateral approach to the shoulder, which permits a better preservation of the axillary nerve compared with the lateral approach and at the same time is less invasive than the deltopectoral approach.

The objective of our study was to find a safe area in the deltoid muscle for the transdeltoid approach and to evaluate the relationships of the PHILOS plate screws with the intramuscular branches of the nerve, analyzing also the different patterns of this nerve compared with those described in the literature. Zhao et al[31] identified 3 different patterns, another pattern is described by Rouviere and Delmas,[26] and another one by Chiarugi and Bucciante.[8] Only Uz et al[28] and Loukas et al[21] have evaluated the terminal branches of the axillary nerve into the deltoid muscle through dissection and measurement in adult cadavers.

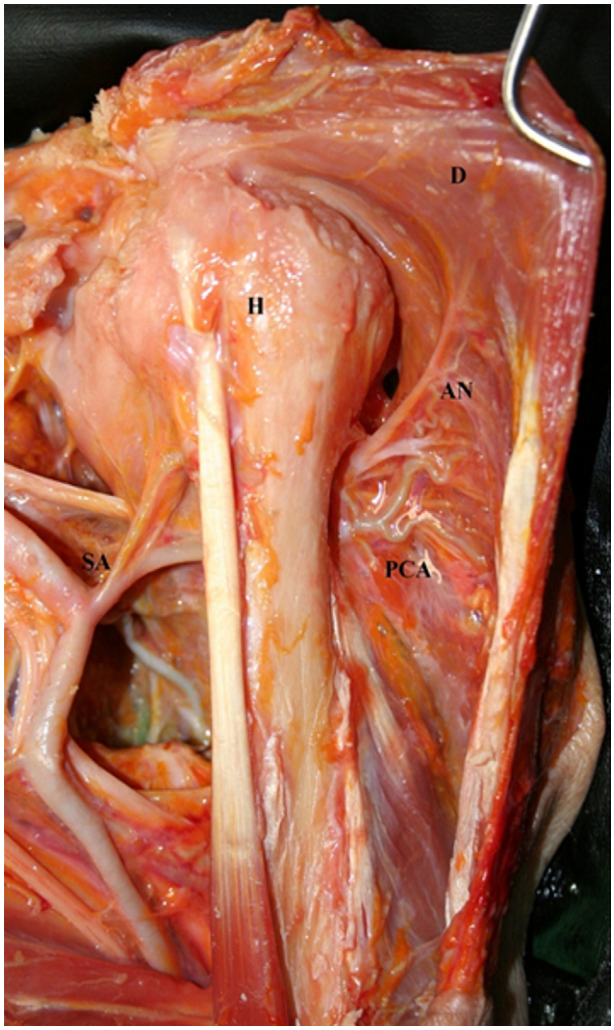


Figure 1 This dissection of the left shoulder (anterior view) shows the humerus *(H)*, the posterior humeral circumflex artery *(PCA)* that originates from the subclavian artery *(SA)*, and the axillary nerve *(AN)* with its branches for the deltoid muscle *(D)*.

Materials and methods

This research was approved by the Ethical Committee of the Department of Anatomy and Physiology, University of Padova, Italy.

Anatomic study was performed on 16 shoulders of unembalmed cadavers (mean age, 72 years; range, 60-85 years) with no documented or anatomic evidences of shoulder pathology. All the cadavers were placed supine, with the arm along the body. The incision was performed according to the deltopectoral approach and prolonged distally until the humeral insertion of the deltoid muscle. Another perpendicular incision was then performed in the axilla. All the subcutaneous tissues were excised to expose the deltoid and pectoralis major muscles. The distal insertion of the deltoid and the acromion were marked with colored pins. The length of the humerus and the morphology of the deltoid muscle were recorded (Fig. 1).

The pectoralis major muscle was detached from its humeral insertion and was reflected medially, exposing the pectoralis minor and biceps brachii muscles. The brachial plexus was exposed, and the origin of the axillary nerve was identified. The axillary nerve was dissected from its origin to its division into the branches for the deltoid muscle. The points where the axillary nerve and its branches penetrated the deltoid muscle were recorded, using as landmarks the humeral head (distance T-AN) and the acromion. A PHILOS plate (length, 114 mm; 5 shaft holes, X41.903) was placed near the humerus to simulate the osteosynthesis of a fracture of its surgical neck, and the relationships between the holes of the plate and the axillary nerve were analyzed.

Afterwards, the deltoid was completely detached from its insertions, together with the axillary nerve and the posterior circumflex

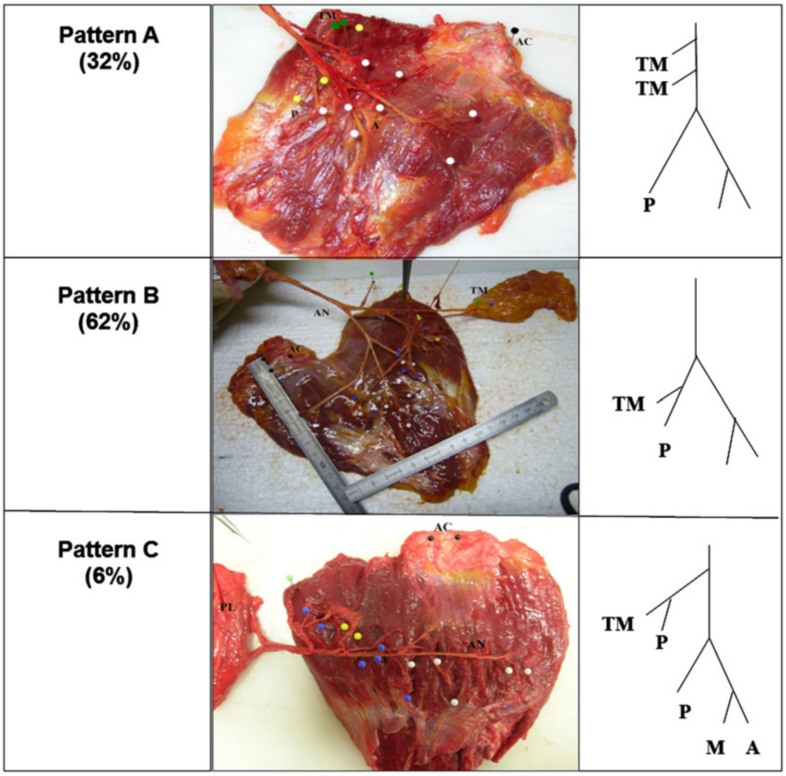


Figure 2 The 3 different patterns of the axillary nerve are shown. The anterior branches of the axillary nerve are highlighted with white pins, and the posterior branches are highlighted with colored pins. *A*, Anterior branch of the axillary nerve; *P*, posterior branch of the axillary nerve; *TM*, branch for the teres minor muscle.

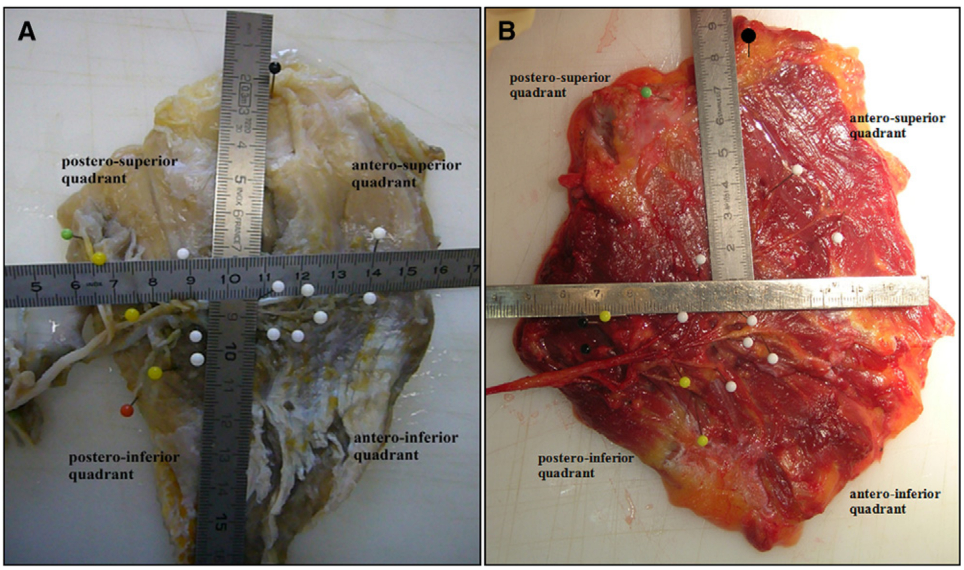


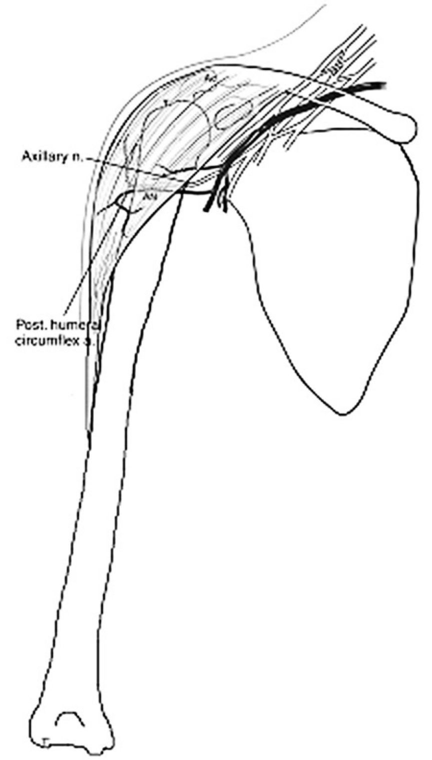
Figure 3 Subdivision in quadrants of the deltoid muscle. It is evident that the anterosuperior quadrant is the less innervated. So, a surgical incision placed at maximum 6 cm from the acromion in this portion of the deltoid muscle could be considered safe for the axillary nerve. The black pin indicates the acromial insertion of the deltoid muscle.

artery. In the dissecting room, the selective dissection of the nerve branches inside the deltoid muscle was performed using a surgical microscope Olympus One (enlargement ×4; Olympus Europa GmbH, Hamburg, Germany). The following distances were recorded, as illustrated in Fig. 2:

- the distance between the origin of the axillary nerve from the brachial plexus and the point where the nerve divided into the anterior and posterior branches (P-S);
- in pattern A and C, the distance between the origin of the nerve respective to the brachial plexus and the origin of the

Table I Measurements of the humerus length (T-T') and of the distance of the axillary nerve from the apex of humerus head (T-AN) and from the acromion (Ac-AN)

Subjects	T-T'	T-AN	Ac-AN
I	28	5.1	7.5
II	30	4.9	7.2
III	30	6.0	7.2
IV	28.5	5.5	6.8
V	30	5.2	6.5
VI	30.5	5.6	6.4
VII	29.5	6.1	6.7
VIII	31	5.8	7.0
IX	29	5.6	6.6
X	31	5.7	6.9
XI	27	5.9	6.8
XII	28.5	6.1	7.2
XIII	32	5.5	6.7
XIV	30.5	5.6	7.0
XV	29	5.6	6.9
XVI	31.5	6.0	7.2
Mean Value	**29.7**	**5.6**	**6.9**
± SD	**1.34**	**0.34**	**0.30**



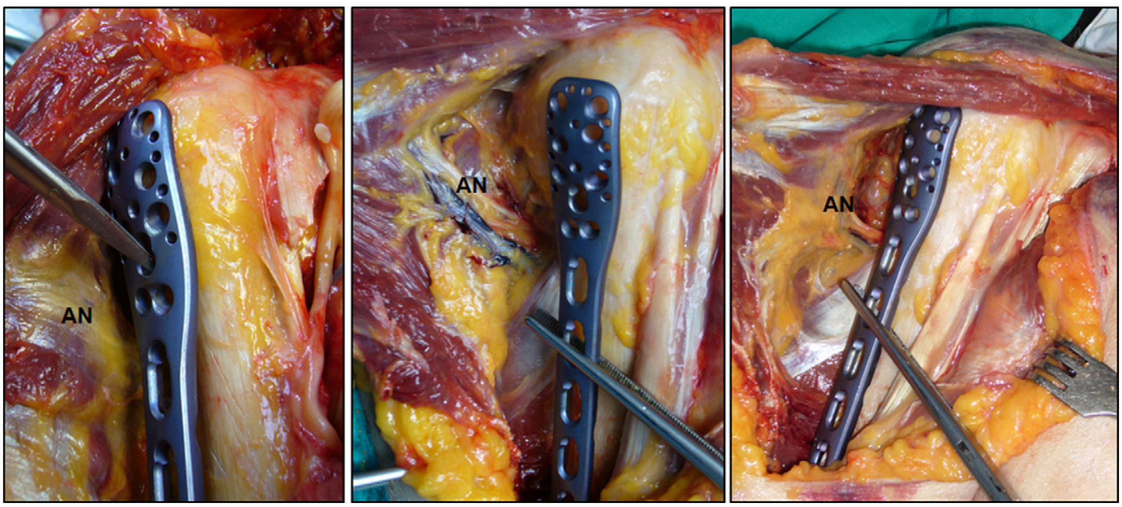


Figure 4 Relationships between the PHILOS plate and the axillary nerve *(AN)*. The insertion of the 2 distal screws of the plate in the holes dedicated to the humeral head could damage the nerve; thus, in the minimally invasive plate osteosynthesis approach, which prevents the direct visualization of the axillary nerve, it is better to avoid insertion of these 2 screws.

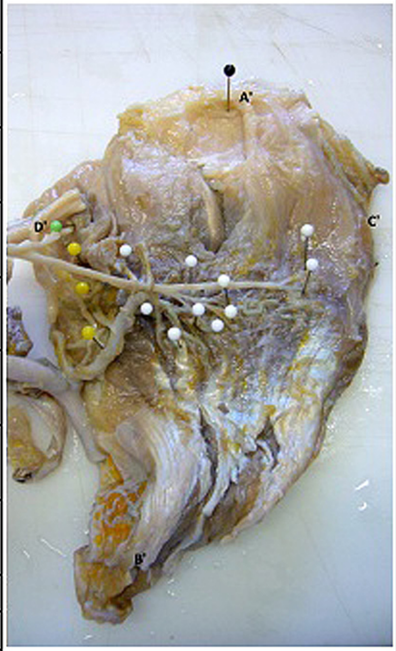
branch for the teres minor muscle (P-S), and the distance between the origin of branch for the teres minor and the point of the axillary nerve where it divides into its anterior and posterior branch (TM-S);

- in pattern B, the distance between the point of subdivision of the axillary nerve and the origin of the teres minor branch.

The posterior circumflex artery was also identified and dissected with all its branches, and the number of branches was recorded.

Table II Measurements of the deltoid dimensions and number of the branches of the axillary nerve and of the posterior circumflex artery (PCA), as highlighted in the dissections of the isolated deltoids

	Deltoid dimensions		N° of branches of axillary nerve			N° of branches of PCA
	A'B'	C'D'	A	P	TM	
I	14	12	8	3	2	6
II	16	15	7	3	1	7
III	16	14.5	5	2	3	6
IV	18	12	10	3	1	11
V	15	12	10	3	1	7
VI	13	13	9	3	2	9
VII	15	14	10	3	1	8
VIII	15	13	7	2	1	7
IX	16	12	6	4	1	7
X	13	12	10	3	1	8
XI	14	13.5	8	3	1	7
XII	15	13	10	2	1	9
XIII	14	14	11	3	1	6
XIV	15	15	8	2	2	8
XV	17	13	7	2	1	7
XVI	16	14.5	8	2	1	8
MV	15.12	13.08	8.37	2.69	1.31	7.56
SD	1.32	1.07	1.65	0.58	0.58	1.27



To understand if a safe zone for the nerves and vessels in the deltoid muscle could be recognizable, the muscle was subdivided in 4 quadrants: anterosuperior, posterosuperior, anteroinferior, and posteroinferior (Fig. 3).

Results

The axillary nerve originated from the posterior cord of the brachial plexus in all examined specimens and descended inferolaterally on the anterior surface of subscapularis muscle to enter in the quadrangular space, where it passed along with the posterior humeral circumflex vessels. Then, it divided into an anterior and a posterior branch. The mean (± standard deviation) distance between the origin of the anterior and posterior branches (AB) was 5.4 ± 0.8 cm. The anterior branch wound around the surgical neck of the humerus and penetrated into the muscle. The posterior branch gave a branch for the teres minor muscle and then penetrated into the posterior part of the deltoid muscle. The principal trunk the axillary nerve gave off a branch for the shoulder joint.

In all specimens, the lateral cutaneus branch of the axillary nerve originated from the posterior branch of the nerve, swept around the posterior border of the deltoid muscle, perforated the deep fascia, and supplied the skin over the posterior part of deltoid muscle and over the long head of the triceps brachii muscle. The posterior humeral circumflex vessels were distributed together with the anterior axillary branch. The mean diameter of the axillary nerve was 0.57 ± 0.44 cm, of the anterior branch was 0.40 ± 0.33 cm, of the posterior branch was 0.33 ± 0.20 cm, and of the teres minor branch was 0.24 ± 0.23 cm.

The mean humeral length, from the head to the trochlea (TT'), was 31 ± 1.48 cm. The mean distance between the point where the axillary nerve enters into the deltoid muscle and the humeral head (T-AN) was 5.0 ± 0.33 cm; from the acromion, it was 6.8 ± 0.30 cm (Table I).

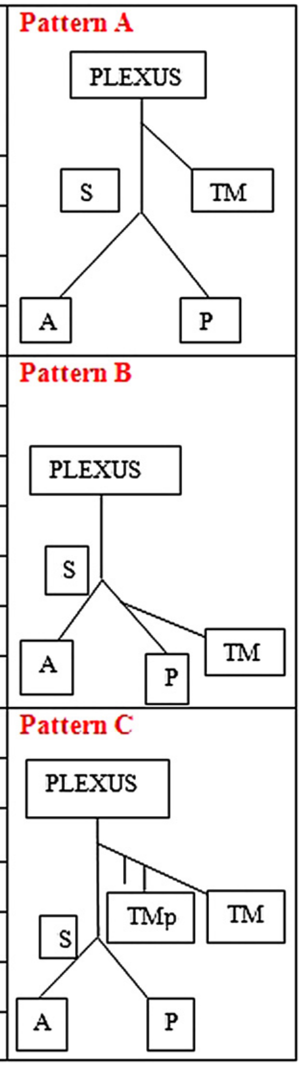
The application of PHILOS plate demonstrated that in 100% of specimens, the 2 distal holes of the plate of those dedicated to the humeral head coincided exactly with the passage of axillary nerve around the surgical neck of the humerus (Fig. 4).

The microscopic dissections permitted us to recognize different nerve branches inside the deltoid muscle; in particular, according to the different origin of the branches, 3 different axillary nerve patterns were identified (Table II).

In pattern A (32%), the anterior branch split into 4 smaller branches, which divided to form 8 smaller ramifications: 6 innerved the middle part of muscle and 2 prolonged into the

Table III Measurements of the distance between the different branches of the axillary nerve from the plexus and from the bifurcation *(S)* between the anterior *(A)* and posterior *(P)* branches. *TM,* Branch for the teres minor muscle

Dissections	Plexus - S (for all the patterns)	Plexus - TM (only for patterns A-C)	TM - S (only for patterns A-C)	S - TM (only for pattern B)
I	4.5	1.9	2.6	
II	2.5	2.0	0.5	
III	5.5	3.4	2.1	
IV	5.4	3.1	2.3	
V	5.4	4.2	1.2	
VI	5.8	4.0	1.8	
VII	3.1			1.5
VIII	4.7			2.5
IX	4.3			1.9
X	5.4			2.1
XI	5.8			2.1
XII	4.6			2.4
XIII	4.8			1.6
XIV	4.1			1.1
XV	3.1			1.7
XVI	2.9			2.2
Mean Value	**4.49**	**3.10**	**1.75**	**1.91**
SD	**1.08**	**0.97**	**0.78**	**0.43**



A, Anterior branch of the axillary nerve, designated in white in the figure; *A′B′* and *C′D′*, length and width of deltoid muscle; *MV,* mean value; *P,* posterior branch of the axillary nerve, designated in yellow in the figure; *SD*, standard deviation; *TM,* branch for the teres minor muscle, designated in green in the figure.

anterior part of deltoid muscle. The posterior branch split into 3 smaller ramifications that innerved the posterior part of deltoid muscle, and a teres minor branch originated from the principal trunk of the nerve.

In pattern B (62%), the axillary nerve split into an anterior branch, which divided into 7 smaller ramifications: 5 innerved the middle part of deltoid muscle, and the other 2 innerved the anterior part of muscle. The posterior branch gave a branch for teres minor muscle and a branch for the posterior part of the deltoid muscle.

In pattern C (6%), the anterior branch split into 5 smaller ramifications: 3 innerved the medial part of the deltoid, and the other 2 innerved the anterior part of this muscle. The posterior branch split into 2 smaller branches that innerved the posterior part of deltoid. The branch for the teres minor muscle originated from the principal branch, but also provided 2 ramifications that innerved the posterior part of deltoid muscle.

The main difference among these patterns was in the teres minor branch: In pattern A, it originated from the principal branch of the axillary nerve; in pattern B, it originated from the posterior branch of the axillary nerve; and in pattern C, it originated from the principal branch of the axillary nerve, but also gave 2 branches that supported the innervation of the posterior part of deltoid muscle.

The main distance between the origin of the axillary nerve from the brachial plexus and the point where the nerve divided into the anterior and posterior branches (P-S)

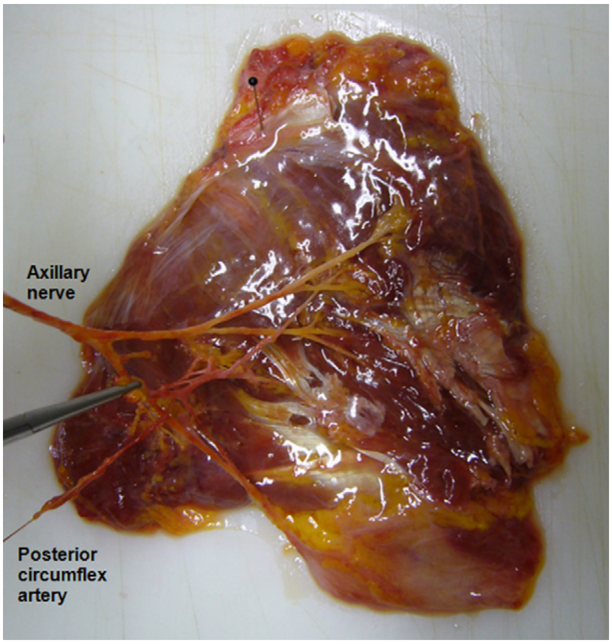


Figure 5 Relationships between the axillary nerve branches and the posterior circumflex artery branches are shown.

was 4.49 ± 1.08 cm; in patterns A and C, the main distance between the origin of the nerve with respect to the brachial plexus and the origin of the branch for the teres minor muscle (P-TM) was 3.10 ± 0.97 cm, and the mean distance between the origin of the branch for the teres minor and the point where the nerve divided into an anterior and posterior branch (TM-S) was 1.75 ± 0.78 cm; in pattern B, the mean distance between the point of subdivision of the axillary nerve and the origin of the teres minor branch (S-TM) was 1.91 ± 0.43 cm (Table III).

The posterior circumflex artery was always visible behind the surgical neck of the humerus, inferior to the axillary nerve. At the level of the deltoid muscle, it split into different smaller ramifications, 7 on average, that were distributed like a fan-shape into the muscle. The posterior circumflex artery branches were interwoven with the axillary nerve branches, so that it could be difficult to separate the vessel and the nerve branches (Fig. 5).

Discussion

Our study identified 3 patterns of axillary nerve: 2 of these correspond to patterns already described in literature, but the third one gave a completely new result (Table II). In particular, pattern A is quite similar to pattern IV described by Rouviere and Delmas,[26] according to which the axillary nerve splits into a branch for the teres minor muscle, an anterior branch for the anterior and middle portions of the deltoid muscle, and a posterior branch for its posterior portion. Pattern B is similar to pattern II described by Pernkopf[24] and by Zhao et al,[31] according to which the anterior branch of the axillary nerve innerves the anterior two-thirds of the deltoid muscle, while the posterior branch gives a branch for teres minor muscle and some branches for the posterior one-third of this muscle. A description similar to pattern C was not found in the literature.

When the deltoid muscle was subdivided in 4 quadrants, the quadrant less innervated in all 16 specimens (100%) was the anterior quadrant. Indeed, usually only 1 small branch of the axillary nerve is recognizable in this quadrant. In comparison, the more innervated quadrants are the posterosuperior and posteroinferior quadrants, where there is a great concentration of branches that derive from the anterior branch of the axillary nerve. The "safe zones" during shoulder surgery, above all during the minimally invasive plate osteosynthesis method, are the anterior quadrants, and in particular, the anterosuperior quadrant. So, to perform a safe surgical incision, the incision should be placed in the anterosuperior quadrant for a length of 6.7 cm from the acromion, which accords with Lill et al[20] and Gardner et al.[13-14]

The anatomic findings of this study suggest also that the anterolateral approach could be preferred rather than the lateral one, at least for the risks of intramuscular nervous branches damage. Indeed, the more the incision is anterior, the more probable it is that it will cut in a zone without intramuscular nervous branches. Our findings also confirm the results of Gardner et al,[13] who have revealed no nerve branches, besides the main motor trunk, crossing the anterior deltoid raphe. So, a clear anatomic knowledge should allow the surgeon to make a safe transdeltoid approach to the proximal humerus, assuring to the patient the advantages of a more rapid recovery and less pain.

The transdeltoid approaches, however, impose the need for careful dissection of the soft tissue and preservation of the innervation; indeed, as highlighted by Hata et al[16] and Hepp et al,[17] atrophy of the deltoid muscle can frequently result. Our evidence of a new axillary pattern (pattern C) has no influence on the choice of the surgical incision, because it gives a variation in the innervation of the posterior portions of the deltoid muscle, and not of the anterior and lateral portions. It is more probable that this variation could assume a role in posterior arthroscopic approaches that could damage the axillary nerve or its branches.[5] The presence of a double innervation of the posterior portion of the deltoid could, theoretically, guarantee a good outcome if a posterior branch is also damaged.

In addition, this study confirms the conclusions of Smith et al,[27] that individuated 3 holes of the PHILOS plate, between those dedicated at the head of humerus, could damage the integrity of the axillary nerve. In particular, these holes of the plate for the humeral head corresponded in 100% of our dissections to the exit of the axillary nerve behind the neck of the humerus. So, the use of the 2 distal screws of those holes for the humeral head should be avoided, above all if the lateral approach has been used. If the surgical plan imposes the use of these screws, we suggest the use of a deltopectoral approach.

Conclusions

From an anatomic point of view, the anterolateral approach is probably preferable to the lateral one because it permits a better preservation of the muscular fibers, and there is less risk of cutting the intramuscular branches of the axillary nerve. In particular, the surgical incision should be performed in the anterosuperior quadrant of deltoid muscle for a maximum length of 6.7 cm from the acromion. In addition, if the orthopedic surgeon uses the transdeltoid approaches to attach a PHILOS plate, the insertion of the 2 distal screws between those dedicated at humerus head of the plate should be avoided.

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