Axillary nerve repair by triceps motor branch transfer through an axillary access: anatomical basis and clinical results

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Object. Grafting or nerve transfers to the axillary nerve have been performed using a deltopectoral approach and/or a posterior arm approach. In this report, the surgical anatomy of the axillary nerve was studied with the goal of repairing the nerve through an axillary access.

Methods. The axillary nerve was bilaterally dissected in 10 embalmed cadavers to study its variations. Three patients with axillary nerve injuries then underwent surgical repair through an axillary access; the axillary nerve was repaired by transfer of the triceps long head motor branch.

Results. At the lateral margin of the subscapularis muscle, the axillary nerve was found in the center of a triangle bounded medially by the subscapular artery, laterally by the latissimus dorsi tendon, and cephalad by the posterior circumflex humeral artery. At the entrance of the quadrangular space, the axillary nerve divisions were loosely connected to each other, and could be clearly separated and correctly identified. Surgery for the axillary nerve repair through the axillary access was straightforward. Eighteen months after surgery, all three patients had recovered deltoid strength to a score of M4 on the Medical Research Council scale and had improved abduction strength by 50%. No deficit was evident in elbow extension.

Conclusions. The axillary nerve and its branches can be safely dissected and repaired by triceps motor nerve transfer through an axillary access. (DOI: 10.3171/JNS-07/08/0370)

Key Words • axillary nerve • brachial plexus • deltid muscle • nerve graft • nerve transfer • neurotization • teres minor muscle

Isolated injury to the axillary nerve can occur because of shoulder dislocation or from inadvertent lesions during surgery, or it may be part of a more complex lesion such as a brachial plexus palsy.2,5,6,12,13,16,20,27,50 Axillary nerve injuries lead to abduction and external rotation weakness.2,15 In brachial plexus injuries, shoulder motion is affected in 95% of cases, and the concomitant involvement of the axillary and suprascapular nerves, due to root lesions, culminates in total palsy on abduction and external rotation.1

In isolated injuries, nerve grafting is the gold standard for treatment and nearly all surgeons use a combined deltopectoral and posterior arm approach.1,5,6,12,17,18,21,25,29 A single report by Sedel13 proposed an axillary approach. The few published papers regarding the anatomy of the axillary nerve only pertain to the risk of lesions during shoulder surgery,4,16 possible entrapment points,28 magnetic resonance imaging,8 surgical landmarks for the deltopectoral approach,29 or anatomy for selective neurotization.3,31

In the present report, the anatomy of the axillary nerve was studied with the intention to repair it via an axillary approach. It was our aim to investigate whether the axillary branches could be individualized and recognized using this approach. Three patients underwent operation, and in these individuals the axillary nerve was repaired by transfer of triceps motor branches through an access in the axilla.

Materials and Methods

Anatomical Studies in Cadavers

The axillae of 10 embalmed cadavers were bilaterally dissected. Dissection was performed through an axillary exposure with the arm abducted and externally rotated (Fig. 1). All the nerves and vessels in the axilla were dissected. After skin incision and subcutaneous tissue separation, the latissimus dorsi tendon was identified. The axillary nerve was located over the subscapularis muscle and its relationship with surrounding structures was studied. This location corresponded to the entrance of the quadrangular space. Branches of the axillary nerve were documented. The latissimus dorsi tendon and the teres major muscle were detached from the humerus and the divisions of the axillary nerve were then further dissected. Next, the relationship of the posterior circumflex humeral artery to the branches of...
Axillary nerve repair

Fig. 1. Line drawing of the cadaver’s position for the anatomical dissection. The right upper limb is abducted and externally rotated. Note the latissimus dorsi tendon (LT) and the axillary nerve (arrow) in the superimposed photograph of the dissection.

the axillary nerve was investigated. The long head of the triceps was detached from the scapula, exposing the teres minor and deltoid muscles. Divisions of the axillary nerve were then entirely dissected and identified.

After dissection was complete, digital photographs were obtained and measurements were made using ImageJ 1.32j software from the US National Institutes of Health. The measured parameters included the distance between the emergence of the axillary nerve from the posterior spinal cord and the latissimus dorsi tendon, the distance between the first division of the axillary nerve and the emergence of the teres minor motor branch, and the diameters of the nerve branches.

Patients Undergoing Operation

Three men (ages 19, 22, and 27 years) with isolated injuries of the axillary nerve underwent surgical repair. All patients clearly had deltoid atrophy; however, the range of shoulder motion was complete. They all reported pain around the shoulder and easy fatigability when raising the arm. Electromyographic evaluation demonstrated no signs of deltoid reinnervation. Time between the injury and surgery was 8 months in one, 9 months in another, and 10 months in the third man. Because of this long interval, we chose not to use nerve grafts but instead to perform nerve transfers, for which triceps motor branches were used. Preoperatively all three patients presented with normal elbow extension strength of 9, 10, and 15 kg, respectively, and abduction strength was 3, 4, and 5 kg, respectively. On average, abduction strength was 40% of that on the normal, contralateral side. Elbow extension strength was measured using a digital hydraulic push-and-pull dynamometer (Baseline, Fabrication Enterprises, Inc.) with the elbow at 90° of flexion. Using the same dynamometer, abduction strength was measured with the shoulder at 45° of abduction.

The patients underwent a final evaluation 18 months postsurgery. Deltoid strength was scored according to the British Medical Research Council scale. Abduction and elbow strength were again measured with the dynamometer at the same limb position.

Results

Anatomical Findings in Cadavers

The axillary nerve emerged from the upper portion of the posterior spinal cord at a mean distance of 49.6 mm (range 28.2–70 mm) medial to the latissimus dorsi tendon. This nerve ran over the subscapularis muscle, passing under the subscapular artery, whereas the radial nerve passed above the artery (Fig. 2A and B). On the subscapularis lateral margin, the axillary nerve was in the center of a triangle bounded medially by the subscapular artery, laterally by the latissimus dorsi tendon, and cephalad by the posterior circumflex humeral artery (Fig. 2C). At the lateral margin of the subscapularis muscle, the axillary nerve divided into an anterior and a posterior branch. The anterior branch was laterally located and it curved around the humerus close to the bone to innervate the anterior and middle portions of the deltoid muscle.

The anterior branch diameter averaged 2.9 mm (range 1.7–3.5 mm). The posterior humeral circumflex artery followed this anterior branch (Fig. 2D). At a mean distance of 12.7 mm (range 9.7–23.5 mm) distal to its origin, the posterior branch divided into a branch to the teres minor muscle and a trunk, which gave rise to the lateral cutaneous nerve in the upper arm, and to the motor branch of the posterior deltoid (Fig. 2A and D). The teres minor motor branch was the most medially located one, and was in close contact with the tendon of the long head of the triceps (Fig. 2B). The entry point of the teres minor motor branch was located on the proximal third of the muscle on its anterior surface (Fig. 3 left). Whereas the diameter for the trunk of the posterior deltoid and the upper arm lateral cutaneous nerve averaged 2.1 mm (range 0.8–3.5 mm), that of the teres minor motor branch averaged 2.2 mm (range 1.2–4 mm). Vascular twigs from the posterior humeral circumflex artery accompanied the nerve branches to the teres minor and posterior deltoid (Figs. 2D and 3 left). No extra- or intramuscular branches from the anterior and middle deltoid branch to the posterior deltoid were seen.

In the entrance of the quadrangular space, the anterior and posterior branches and their divisions were loosely connected to each other and they could be clearly separated by blunt dissection. The deltoid and the teres minor motor branches could be correctly identified and dissected in the proximal limit of the quadrangular space (Fig. 3 right). An articular branch to the shoulder joint that emerged from the lateral side of the axillary nerve before its division into anterior and posterior branches was consistently identified. This articular branch splayed over the lower and inferior portions of the anterior joint capsule (Fig. 2A). The relationship of the axillary nerve to the triceps long head and upper medial head motor branches is depicted in Fig. 4.

Anatomical Variations

In one dissection, all the motor branches arose together and the cutaneous branch emerged separately medially and proximally (Fig. 5 left). In another dissection, the circumflex posterior humeral artery and the circumflex scapular artery arose from a common trunk, and the thoracodorsal artery stemmed directly from the axillary artery. In this variation, the space between the circumflex posterior humeral artery and circumflex scapular artery was restricted, thus complicating dissection of the axillary nerve. In three other dissections, the posterior circumflex humeral artery and circumflex scapular artery was restricted, thus complicating dissection of the axillary nerve. In three other dissections, the posterior circumflex humeral artery and circumflex scapular artery originated from the subscapular artery, but the triangle of the axillary nerve was not narrow. In one case, the posterior humeral circumflex artery had a reduced diameter and the branch to the teres minor muscle originated from the subscapular artery. In one dissection, the posterior branch of the axillary nerve perforated the long head of the triceps (Fig. 5 right).
Surgical Exposure of the Axillary Nerve and the Radial Nerve Through the Axillary Approach

After induction of general anesthesia, the patients were placed supine and the operation was begun. The incision was designed to extend from the middle of the axilla to the upper arm over the brachial vessels (Fig. 6). The axillary vein was traced from the upper arm to the axilla, and cephalad retraction was applied as needed. The radial nerve was dissected while the triceps upper medial and long head motor branches were individualized and stimulated electrically for proper identification. The triceps long head motor branch was most cephalad and its entry point into the long head of the triceps confirmed its identity. The involved limb was abducted and externally rotated, and the tendon of the latissimus dorsi was identified. Dissection progressed toward the medial border of the latissimus dorsi tendon and

**Fig. 2.** Photographs. A: Anatomical dissection of the right axilla after detachment of the latissimus dorsi tendon (LTD) and the teres major (TMa) from the humerus. The axillary nerve (Ax) ran over the subscapularis muscle (Sbm), passing under the subscapular artery (Sa). Note the divisions of the axillary nerve into an anterior branch (AD) to the anterior and middle deltoid and a posterior branch that further divided into a branch to the teres minor (TMb) and another to the posterior deltoid and to the skin over the deltoid muscle (PDC). The teres minor branch was close to the long head of the triceps (Tlo). The anterior branch of the axillary nerve was adjacent to the posterior circumflex humeral artery (PCA). The white star indicates the humeral head, whereas the black star points out the teres minor muscle. Ar = articular branch of the axillary nerve. B: Anatomical dissection of the left axillary nerve (Axn). The axillary nerve passed under the subscapular artery, whereas the radial nerve (RN) ran above it. Distal to the subscapular artery, the axillary nerve divided into an anterior (Ab) and a posterior branch (Pb). Note the teres minor branch (Tmb) close to the insertion of the long head of the triceps. Axa = axillary artery; PCHA = posterior circumflex humeral artery; PDb = branch to the posterior deltoid and the upper arm lateral cutaneous nerve. C: Anatomical view of the triangle of the axillary nerve in the right axilla. The axillary nerve was found in the center of a triangle bounded medially by the subscapular artery, laterally by the latissimus dorsi tendon, and cephalad by the posterior circumflex humeral artery. Note the accompanying veins (white stars) of the subscapular artery and the posterior circumflex humeral artery. The veins were located medially to the arteries. D: View of an anatomical dissection of the left axilla after removal of the latissimus dorsi and teres major tendons (LTm) and the long head of the triceps. In this dissection, the posterior circumflex humeral artery (PCHa) exceptionally arose from the subscapular artery. The posterior circumflex humeral artery curved around the humerus together with the anterior branch of the axillary nerve. The teres minor and the posterior deltoid nerve and artery are visualized. The posterior branch of the axillary nerve did not curve around the humerus but instead divided to innervate the teres minor (TMm) and posterior deltoid muscles (PDM). Note the upper arm lateral cutaneous nerve (ULCn). The star indicates the origin of the axillary nerve from the posterior spinal cord. The subscapular artery divided into the circumflex scapular artery (Sca) and thoracodorsal artery (Ta). Sm = subscapularis muscle; Tl = triceps lateral head.

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the lateral border of the subscapularis muscle. The quadrangular space was palpated and the axillary nerve was identified. The axillary nerve was located in a triangle bounded by the latissimus dorsi tendon, posterior circumflex humeral artery, and subscapular artery. A retractor was placed in the latissimus dorsi tendon and teres major to further expose the axillary nerve branches and the long head of the triceps. The latissimus dorsi and teres major were laterally retracted. This maneuver does not put the thoracodorsal nerve at risk because this nerve enters the latissimus dorsi muscle more caudally. The anterior and middle deltoid branch was the most laterally located, curving around the humerus, whereas the teres minor branch was close to the long head of the triceps. The branch to the deltoid and the branch to the teres minor were sectioned and turned distally, then the triceps long head motor branch was sectioned, turned proximally, and coapted to the deltoid and teres minor branches (Figs. 4, 7A, and 7B). In one patient, the triceps long and medial head motor branches were used because the long head presented a reduced diameter (Fig.

![Image](https://via.placeholder.com/150)

**Fig. 3.** Left: Anatomical view of the right axilla after detachment of the teres major, latissimus dorsi, and long head of the triceps. The star indicates the humeral head. Note that the motor entry point (black arrow) of the teres minor muscle (TM) is located on its anterior surface. PDb = posterior deltoid artery branch; PDnb = posterior deltoid nerve branch; TMab = teres minor artery branch; TMnb = teres minor nerve branch. Right: Dissection of the right axillary nerve in the quadrangular space. At this location, the branches of the axillary nerve were packaged together, but loosely connected, which permitted individualization of all the branches. Lateral retraction of the latissimus dorsi tendon (LDT) and teres major allowed the visualization of the motor entry point of the teres minor, confirming the identity of all the branches. PDb = posterior deltoid and upper lateral cutaneous nerve of the arm.

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**Fig. 4.** Left: Anatomical dissection of the right axilla showing the relationship of the axillary nerve and the triceps long (Lo) and upper medial head (M) motor branches. The axillary nerve is located on the medial border of the latissimus dorsi tendon, whereas the triceps motor branches are located on its lateral border. TD = thoracodorsal nerve. Right: Drawing of the transfer of the triceps long head motor branch to the anterior and middle deltoid branches and to the teres minor branch. The posterior division of the axillary nerve is left in continuity.
The triceps long head motor branch was coapted to the deltoid and teres minor motor branches, then the incision was closed in layers and the skin was sutured.

Clinical Cases
Surgery was completed without complications. Eighteen months after surgery, all patients had deltoid reinnervation with restoration of the shoulder contour. Resisted elbow extension clearly elicited deltoid contraction. Shoulder pain and fatigability had disappeared. The deltoid strength was M4 in all patients and triceps strength was preserved. Abduction strength improved by 3, 2, and 2 kg, respectively.

Discussion
Anatomical Findings
The pattern of axillary nerve branching was predictable and in accordance with most recent reports. Variations on the axillary nerve are almost entirely related to the level of divisions and emergence of the nerve branches. We observed that both the deltoid and the teres minor motor branches could be individualized by the axillary approach. The branch to the anterior and middle deltoid was close to the posterior circumflex humeral artery, whereas the posterior branch, particularly the teres minor motor branch, was close to the long head of the triceps. In addition, the anterior but not the posterior branch curved around the humeral neck. The posterior branch had a direct course toward the teres minor and posterior deltoid. The teres minor motor branch consistently reached the teres minor muscle by its anterior surface on its proximal third. This finding differs from those of Sunderland and Hovelacque, who proposed that the motor entry point of the teres minor was posterior and inferior. Ball et al. observed that the posterior deltoid received innervation from the branch to the anterior-or and middle deltoid (that is, the anterior branch). These authors did not find the branch to the posterior deltoid from the posterior axillary nerve branch in five of 20 specimens dissected. In 90% of dissections, Zhao et al. identified a branch to the posterior deltoid stemming from the posterior division of the axillary nerve, as did we. In contrast to our findings, however, in 57.5% of their dissections they also identified a branch from the anterior division of the axillary nerve to the posterior deltoid. We were unable to confirm such observations; in our dissections, the posterior branch of the axillary nerve always and exclusively innervated the posterior deltoid muscle. Hong et al. published similar findings. The discrepancy between our results and those from Ball et al. and Zhao et al. is probably related to how the posterior deltoid muscle boundaries were determined. We observed that before entering the middle deltoid muscle the motor branch arborized. Therefore, one of these terminal branches could possibly be considered a branch to the posterior deltoid.

Approach to the Axillary Nerve Through the Axilla
The latissimus dorsi tendon was a useful guide to locate the axillary nerve. With the arm abducted and externally rotated (the position of the dissection), palpation against the humeral head of the interval between the latissimus dorsi tendon and the subscapularis muscle aided precise identification of the axillary nerve. This nerve was consistently located in the center of a triangle determined by the posterior humeral circumflex artery, subscapular artery, and the latissimus dorsi tendon. Although the axillary nerve could be exposed by the axillary approach, its more proximal portions were difficult to dissect. We believe that the deltopectoral approach is preferable for the proximal dissection of axillary nerve origin.

On the other hand, the axillary approach proposed here is particularly interesting for repairs in which triceps motor...
nerve transfers are used. This approach is feasible because the long head motor branches of the triceps originate proximally in the axilla, over the latissimus dorsi tendon.\textsuperscript{11,24,25} Because the axillary nerve branches can be individualized, selective neurotization, excluding the cutaneous branch, can be performed. We have previously transferred triceps branches to the axillary nerve by a separated posterior arm approach.\textsuperscript{5} Dissection of the teres minor branch is much more difficult via the posterior approach. In addition, the axillary approach is safer because all major vessels are under visual control. In axillary nerve injuries amenable to grafting, combining the deltopectoral approach with the axillary access in lieu of the posterior arm access might be desirable, because the length of the nerve grafts is shortened.

In entrapment syndromes of the axillary nerve (that is, quadrangular or quadrilateral space syndrome), a posterior arm approach is recommended for surgical decompression and for lysis of fibrous tissue.\textsuperscript{10} Nevertheless, from a posterior arm approach neither the axillary nerve trunk nor the posterior circumflex humeral artery can be adequately exposed. The axillary access proposed here is more appropriate because not only the branches but also the axillary nerve trunk can be explored.

Clinical Features

Whether a deficit exists after axillary nerve injury has been controversial.\textsuperscript{25} Kline and Kim\textsuperscript{12} indicated that axillary nerve lesions accounted for decreased range of abduction. In contrast, Bonnard et al.\textsuperscript{6} and Sedel\textsuperscript{23} recognized that full abduction is possible in patients with axillary nerve lesions, in agreement with observations made by surgeons of the last century.\textsuperscript{7} Sunderland\textsuperscript{25} stated that in axillary nerve lesions the final functional deficit is a reduction in strength rather than in the range of abduction. Patients who are seen early present with decreased range of abduction. Later on,

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\caption{Line drawing of the surgical incision to repair the axillary nerve through the axilla.}
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\caption{Photographs showing intraoperative views in the three patients who underwent axillary nerve repair through an axillary access. A: First patient. The axillary nerve has been dissected and its branches identified; the teres minor motor branch (Tm), anterior and middle deltoid branch (D), and cutaneous and deltoid posterior branch (C) are shown. Also, the radial nerve has been dissected and the long and upper medial head motor branches have been individualized. The inset shows the appearance of the coaptation of the triceps long head motor branch to the teres minor and deltoid branches. B: Second patient. The axillary nerve has been dissected and its branches identified. In the left inset note the teres minor motor branch (Tmb), anterior and middle deltoid branch, and the cutaneous and deltoid posterior branch. A retractor (arrow) is pulling the latissimus dorsi (LD) tendon laterally and the teres minor muscle (Tmm) motor entry point is visualized. Lateral retraction of the latissimus dorsi tendon is safe because the thoracodorsal nerve and vessels enter the latissimus dorsi muscle more caudally. In the main photograph, the radial nerve has been dissected and the long head and upper medial head (Um) motor branches were individualized. Note the cutaneous (Cu) branch from the radial nerve. The right inset shows the appearance of the coaptation of the long head of the triceps and its divisions with the teres minor and deltoid branches. C: Third patient. The axillary nerve has been dissected and its branches identified. A retractor is pulling the latissimus dorsi tendon laterally and the axillary nerve divisions are clearly visualized. In the left inset note the teres minor motor branch, anterior and middle deltoid branch, and the cutaneous and deltoid posterior branch. The right inset shows the appearance of the coaptation of the long head of the triceps with the anterior and middle deltoid branch and the upper medial head branch with the teres minor motor branches. There was a common trunk of origin from the radial nerve for the triceps long and upper medial head motor branches. Both triceps motor branches were used for the neurotization of the axillary nerve.}
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as occurred in our cases, full abduction may be restored by hypertrophy of the supraspinatus muscle. It is uncertain that all patients with chronic lesions of the axillary nerve fully recover the range of abduction, but certainly a number of them do recover without nerve repair. In our opinion, when a deficit of abduction persists, the supraspinacular nerve and/or the rotator cuff also have been injured. In this connection, Bonnard et al. recommended exploratory surgery if by the 3rd month postoperatively no clinical or electromyographic signs of deltoid reinnervation are present. Occasionally, however, paralysis of the axillary nerve goes unnoticed and referral for treatment is delayed. Alnot and Valenti believe that, until 12 months postinjury, nerve repair is warranted. Despite longstanding palsy, our patients presented with clear deltoid atrophy and no clinical or electromyographic signs of reinnervation. They sought medical help because of shoulder pain and tiredness, but had a normal range of abduction. According to Nunley and Gabel, in young patients with a normal range of abduction but decreased strength, nerve repair surgery might be indicated because the prognosis for shoulder function is uncertain. Due to the unfavorable outcomes of tendon transfer for shoulder abduction reconstruction, we believe that surgery should be proposed for all young patients with axillary nerve injury that has occurred within 1 year previously. In this connection, we elected for a nerve transfer close to the deltoid muscle because there is a dramatic decrease of nerve grafting success in lesions older than 5.3 months. Indeed, we have obtained an improvement of 50% in the strength of abduction, which validates our strategy. The results obtained here cannot be compared to reported series of graft repair for two reasons. One, the number of patients is small. Two, we lack objective measurements of the abduction strength in graft series. Moreover, we were unable to find other reports of triceps transfers, or any other transfer for the treatment of isolated axillary nerve lesions.

Triceps motor branch activity is synergic to shoulder abduction and external rotation, contrary to other possible donor nerves for transfer such as the thoracodorsal, medial pectoralis, and subscapularis. This facilitates the postoperative reeducation of the teres minor and deltoid muscles after axillary nerve transfer. Narakas observed that in two patients in whom the thoracodorsal was connected to the axillary nerve, no phasic conversion of deltoid function, which ultimately contracted when the limb was adducted, was present. The accessory nerve innervates the trapezius muscle, which is synergic to deltoid function; however, its use as a donor for transfer to the axillary nerve needs the interposition of a nerve graft. No permanent deficit in triceps function occurred, and this outcome agrees with previous reports. This is because the triceps medial and lateral heads remained innervated and probably had hypertrophied.

Conclusions

The axillary nerve and its branches can be dissected via the axilla and repaired by a triceps motor branch transfer. In paralysis lasting more than 8 months but less than 12 months, a triceps motor branch transfer to the axillary nerve might be considered as an alternative for grafting.

Acknowledgment

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References

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