Neurotization of the Axillary Nerve: A Case Series and Review of the Literature

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Abstract

Background data: Axillary nerve is one of the branches of the posterior cord of the brachial plexus that carries nerve fibers from C5 and C6 roots and then travels to innervate the deltoid muscle and teres minor muscle; it maintains stability of the shoulder joint and provides sensation to the overlying skin. Many techniques are present to manage axillary nerve injuries according to the applied anatomy to provide more safety during exploration. It may be isolated or combined injury, and each type has its specific protocol.

Study design: This is a retrospective clinical case study.

Patients and methods: Between January 2018 and December 2019, eight male patients with an average age of 32.2 years (range, 20–45 years) presented with complete loss of shoulder abduction. All of the patients underwent microsurgical axillary nerve neurotization using transfer of the part of the radial nerve of the medial head of the triceps and suturing it into the stump of the axillary nerve. The posterior approach in the prone position was used in all patients. The axillary nerve stump was proximal to the origin of the nerve to teres minor muscle. The surgical intervention was done for all eight patients by the same team. Preoperative and follow-up clinical evaluation was done by assessing the motor power of all the patients, which was clinically evaluated using the Motor Research Council scale. The mean follow-up period was 12 months.

Results: A total of eight male patients who presented after a history of traumatic insults were included in the study. The average lapse between the traumatic insult and the surgical intervention was 5 months (range, 4–6 months). Shoulder abduction was grade 0 in all patients on the Motor Research Council scale. Five patients had complex deficits all over the upper limb among brachial plexus injuries, whereas three had isolated axillary nerve deficits. Overall, 62% of the patients (five patients) showed marked functional motor improvement, whereas three patients did not show any improvement. Mean time of the surgery was about 80 min. The mean amount of blood loss was 160 ml. The average period of recovery was 6 months, whereas the mean period of follow-up was 32 months.

Conclusion: Harvesting the stump of the axillary nerve proximal to the takeoff of the branch of the teres minor muscle while suturing it with the radial nerve stump through the procedure of nerve transfer is the cardinal step for achieving functional motor recovery by gaining shoulder abduction (2021ESJ251).

Keywords: Axillary nerve, Nerve transfer, Posterior approach, Shoulder abduction, Teres minor

Introduction

Shoulder abduction is an important movement in achieving proper function of the upper limb as a whole [1]. This is achieved by proper shoulder movements by the shoulder joint. The shoulder joint is one of the multiaxial joints all over the body and is classified as a synovial ball and socket joint. It resembles the articulation between the glenoid cavity of the scapula and the head of the humerus. Abduction is carried out by the deltoid and supraspinatus muscles [2,3]. Deltoid muscle is innervated by the axillary nerve, whereas the supraspinatus muscle is
innervated by the suprascapular nerve, but both share the cervical root value (C5, C6) from the spinal cord [4,5]. The axillary nerve originates from the posterior cord and turns backward, passing through the quadrangular space accompanied by the posterior circumflex humeral artery and vein [5]. Deltoid muscle is a triangular muscle that consists of the anterior part, lateral part, and posterior part [3]. The lateral part contributes to the shoulder abduction, whereas the anterior and posterior parts do much helping to start the shoulder adduction [5,6]. Supraspinatous muscle originates from the supraspinatus fossa, and its tendon passes laterally and is inserted into the greater tubercle of the humerus [7]. Teres minor muscle is a rounded, elongated narrow muscle that originates from the lateral border of the scapula and is directed obliquely upward and laterally to be inserted into the greater tubercle of the humerus, whereas the lower fibers are ended into insertion on the humerus below this tubercle [1,3,5].

The importance of this study is magnifying the importance of the anatomical dissection of the axillary nerve with its branches before completing the procedure of the nerve transfer with the donor nerve [3,5]. This is rationalized as the guidelines in the procedure of the nerve transfer mention the importance of innervation of the key muscles that are supposed to be regained in function. Here, we mention the teres minor muscle and its nerve supply from the axillary nerve.

This study aims to describe the intraoperative details concerning the neurotization of the axillary nerve and the proper site of harvesting its stump for suturing in neurorrhaphy.

Patients and methods

Between January 2018 and December 2019, in the Damanhour Medical National Institute, Department of Neurosurgery, eight male patients with an average age of 32.2 years (range, 20–45 years) presented with complete loss of shoulder abduction. All of them were treated by neurotization of the axillary nerve by part of the branch of the radial nerve to the media head of the triceps muscle through microscopic surgical intervention. Preoperative and follow-up clinical evaluation was done by assessing the motor power of all the patients using the Motor Research Council (MRC) scale. The mean follow-up period was 12 months. The World Medical Association (WMA) Declaration of Helsinki, Ethical Principles for Medical Research Involving Patients was followed. All patients consented to the surgical intervention and research purposes to publish the medical data. The study was approved by our IRB.

Surgical technique

All patients underwent the operation in a prone position under general anesthesia with endotracheal intubation without using neuromuscular blocking agents. Posterior approach was used through a longitudinal skin incision over the posterior edge of the deltoid muscle directed to the back of the arm over the triceps muscle. Meticulous dissection in layers was done. At the beginning of the dissection, it was common to face the sensory branch of the axillary nerve, so with retrograde dissection of this branch, we could reach the main division of the axillary nerve; then, by further dissection, the axillary nerve appeared properly in the quadrangular space. With the anterograde approach, we determined the branch to teres minor muscle and the other superior and inferior branches and performed external neurolysis. Using an intraoperative nerve stimulator, we tested the axillary nerve for the possibility that it was functionally intact after this external neurolysis. If we got a positive response (shoulder abduction) by the intraoperative stimulator, we ended the surgery, and after recovery from anesthesia, the patient continued through the rehabilitation program to stimulate the axillary nerve itself. In this study, all of the patients showed no response after intraoperative stimulation. Thus, we elongated the skin incision over the back of the arm. Splitting the longitudinal and lateral heads of the triceps muscle and meticulous dissection to determine the radial nerve proper and its branch to the long head were performed. We performed external neurolysis of this branch, then opened the epineurium, and did internal neurolysis of the fascicles. We identified about a fifth of those fascicles and harvested them as distal as possible to gain a length that allows for tensionless neurorrhaphy. Then, we turned to the axillary nerve proper and cut it proximal to the takeoff of the branch to teres minor muscle. The two stumps (axillary nerve stump as recipient and nerve to the long head of triceps as donor) were approximated and sutured using 7/0 polypropylene. Moreover, we put some pieces of fat over the suture line of this neurorrhaphy to avoid adhesions over it and then applied closure in layers. After the closure of the sheath of the triceps muscle, we put the drain between the skin and muscle sheath.

Statistical analysis

Data were analyzed using Statistical Package for the Social Sciences (SPSS Inc., Chicago, Illinois, USA). Quantitative data were expressed as a
mean ± SD. Moreover, qualitative data were expressed as frequency and percentage. Independent sample *t* test of significance, paired sample *t* test of significance, and *P* value were used. *P* value less than 0.05 was considered significant, whereas *P* value more than 0.05 was considered insignificant.

**Results**

The reported eight patients were 6 males and 2 females who presented after a history of traumatic insults (Table 1). The average between the traumatic insult and the surgical intervention was about 5 months (range, 5–10 months). All of them underwent physiotherapy programs to maintain joint mobility and muscle contour. Moreover, clinical follow-up was done for all patients till deciding on the surgical intervention when the conservative management with physiotherapy failed to regain the functional recovery of the shoulder joint. Electrophysiological monitoring studies, including electromyography and nerve conduction velocity, were done for all patients in the preoperative period. Motor power was evaluated in all patients’ perioperative period using the MRC scale. Shoulder abduction above 15° was grade 0 in all patients on the MRC scale. Surgical intervention was done using the posterior approach and prone position in all patients. The axillary nerve stump was proximal to the takeoff of the nerve to teres minor muscle. All the patients underwent axillary nerve neurotization using transfer of part of the radial nerve of the medial head of the triceps and then suturing it into the stump of the axillary nerve. The surgical intervention was done for all eight patients by the same team, and neurorrhaphy was done in a microscopic fashion. The mean time of the surgery was about 80 min. The mean amount of blood loss was 160.8 ml. No added deficits happened in all patients. One patient underwent a superficial wound infection and was managed medically by frequent daily dressing for about two weeks. All of the patients underwent considerable time in the rehabilitation physiotherapy programs postoperatively.

Five (62%) patients showed a marked functional motor improvement, whereas three patients did not show any functional motor improvement. The average period of recovery was 6 months, whereas the mean period of follow-up was 12 months.

**Discussion**

The shoulder joint is a multiaxial spheroidal joint with wide mobility. The shoulder complex comprises four joints: the glenohumeral joint (main joint), scapulothoracic joint, sternoclavicular joint, and

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<th>Cases</th>
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<th>Denervation time (months)</th>
<th>Surgical procedure</th>
<th>Shoulder abduction &gt;15°</th>
<th>Outcome of shoulder abduction &gt;15°</th>
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<td>1</td>
<td>20/M</td>
<td>Motor bike</td>
<td>6</td>
<td>Radial nerve to axillary nerve</td>
<td>Grade 0</td>
<td>Recovered to MRC +4</td>
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<td>2</td>
<td>25/F</td>
<td>Motor bike</td>
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<td>Direct trauma</td>
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<td>Radial nerve to axillary nerve</td>
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<td>4</td>
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F, female; M, male; MRC, Motor Research Council.
acromioclavicular joint [8]. The muscles of the shoulder complex that maintain its stability are the supraspinatus muscle, deltoid muscle, infraspinatus muscle, and teres minor muscle. They contribute to each other to provide a smooth wide range of movements, including abduction, internal rotation, external rotation, flexion, and extension [8]. The axillary nerve originates from the posterior cord of the brachial plexus at the level of the axilla. It contains nerve fibers from C5 and C6 roots. It starts laterally to the radial nerve and posterior to the axillary artery and anterior to the subscapularis muscle. Then, it turns backward and divides into anterior and posterior branches. The anterior division supplies the anterior part of the deltoid muscle after curving around the surgical neck of the humerus. The posterior division supplies the teres minor muscle and posterior part of the deltoid muscle and then continues as the lateral brachial cutaneous nerve [3,8].

Uz et al. [9] have reported an anatomical study about the anatomical patterns of the axillary nerve, including its main segment and branches. They studied 30 shoulders in 15 adult cadavers using microscopic dissection. In all cases, they reported that the posterior branch of the axillary nerve gave off its first muscular branch to innervate the teres minor muscle. Moreover, the posterior part of the deltoid muscle was innervated by a branch or branches coming only from the posterior branch in 70% of the cases, from the both anterior and posterior branches in 26.7% of cases, and from the anterior branch only in 3.3% of cases [9].

Moreover, Uz and colleagues have reported the main length of the axillary nerve branches as follows: nerve to teres minor muscle is 2.4 cm, nerve to the posterior part of the deltoid muscle is 4.4 cm, nerve to acromial part of the deltoid muscle is 3.6 cm, nerve to the clavicular part of the deltoid muscle is 6.3 cm, and superior lateral brachial cutaneous branch is 7.7 cm [9].

The posterior division of the axillary nerve innervates about 70% of the deltoid muscle, and the branch to teres minor muscle is the first branch originating from this posterior division, so harvesting the axillary nerve while performing the neurotization of the axillary nerve is mandatory [9].

The axillary nerve originates from the posterior cord and turns backward, passing through the quadrangular space accompanied by the posterior circumflex humeral artery and vein [3]. Axillary nerve comprises three main parts: the trunk, anterior branch, and posterior branch. The anterior branch turns backward around the surgical neck of the humerus and provides the motor innervation for the deltoid muscle and sensation for the skin over the shoulder [1]. The posterior branch provides motor innervation for the teres minor muscle and posterior part of deltoid muscles and provides sensation for the skin over the lower arm via the lateral cutaneous nerve of the arm [1,3,5] (Fig. 1). The deltoid muscle is a triangular muscle that consists of the anterior part, lateral part, and posterior part. The lateral part contributes to the shoulder abduction, whereas the anterior and posterior parts do much helping starting the shoulder adduction. The anterior part originates from the anterior border and upper surface of the lateral third of the clavicle and assists in shoulder flexion [5]. The origin of the lateral part of the deltoid muscle is the acromion process of the scapula and is considered the main abductor of the shoulder, whereas the posterior part originates from the lower lip of the posterior border of the spine of the scapula and assists in shoulder extension. The muscle fibers of those three parts converge into their insertion on the deltoid tuberosity in the middle of the lateral aspect of the shaft of the humerus [1,6]. Supraspinatus muscle originates from the supraspinatus fossa, and its tendon passes laterally and is inserted into the greater tubercle of the humerus [7]. It abducts the arm and is one of the rotator cuff muscles. It is innervated by the suprascapular nerve, with a root value (C5) from the spinal cord. It works in cooperation with the deltoid muscle to perform shoulder abduction beyond 15° [6,7,11]. Teres minor muscle is a rounded, elongated narrow muscle that originated from the lateral border of the scapula and is directed obliquely upward and laterally to be inserted into the greater tubercle of the humerus, whereas the lower fibers are ended into insertion on the humerus below this tubercle (Fig. 1). It is
innervated by the posterior branch of the axillary nerve (C5, C6) from the spinal cord. It is one of the rotator cuffs and prevents the upward sliding of the head of the humerus, while the arm is abducted and rotating the humerus laterally [1,5,6,12].

While performing radial nerve (the portion of a branch of the medial head of triceps muscle) transfer to the axillary nerve through the posterior approach in a prone position, skin marking was done over the line along the posterior border of the deltoid muscle, between the long head and lateral head of triceps muscle (Fig. 2A) [4,6,7,12]. Teres major muscle is the key muscle and the main landmark in dissection as it lines the quadrangular and triangular spaces [3,4,7,13]. Quadrangular space transmits axillary nerve and is lined by teres major muscle inferiorly, teres minor muscle superiority, long head of triceps muscle medially, and humerus laterally [1,7,14,15]. Triangular space transmits the radial nerve and is lined by teres major muscle superiority, long head of triceps muscle medially, and the lateral head of triceps muscle laterally [4,12]. The branch of the radial nerve that supplies the medial head of triceps muscle is running close to the main trunk of radial nerve proper. The sensory branch of the axillary nerve is the key nerve in the step of surgical exploration [1,4,6,12,14,16]. Sensory fibers of the axillary nerve are located inferiorly to the axillary nerve, whereas the motor component contains the upper three quadrants of the nerve [4,6,7,12,14,15,17].

The axillary nerve is divided into two main divisions (anterior and posterior) [12]. While performing the neurorrhaphy between the two stumps (axillary stump and radial nerve stump), we harvested the most proximal point of the axillary nerve, which must be proximal to the takeoff of the branch to teres minor muscle and then transposed it inferiorly toward the radial nerve stump (the superiorly transposed branch of the radial nerve of the medial head) (Fig. 2B, C) [4,11,16]. Cutting the sheath of the inferior tendinous edge of the teres major muscle reduces the tension and traction over the site of the suturing and gains more tensionless neurorrhaphy (Fig. 2D) [12,17].

It is believed that restoring better shoulder functional improvement is achieved by gaining the shoulder abduction and external rotation by neurotization of the axillary nerve and suprascapular. Moreover, neurotization of the nerve branch of teres minor muscle adds significant functional importance as it provides glenohumeral capsular stability and maintains the external rotation [14]. So, it is important to involve the branch to teres minor muscle in the reconstructive plant in the neurotization process [7,14]. Harvesting of the axillary nerve stump proximal to the takeoff of the branch of the teres minor muscle is a cardinal step in the surgical intervention in this procedure of nerve transfer [7,11,16] (Fig. 3).

In 2011, Jerome [13] published a study about the long head of the triceps branch transfer to the axillary nerve in brachial plexus injuries via an anterior approach. He claimed that the posterior approach for axillary nerve reconstruction causes excessive traction on the deltoid muscle and a high possibility of injury to the posterior branch of the axillary nerve plus shows difficulty in dissecting the nerve of teres minor muscle, which is important in neurotization.
Moreover, Ray et al. [10] have reported the importance of including the teres minor nerve branch in axillary nerve neurotization. Furthermore, they recommended the anterior approach for harvesting the axillary nerve as proximal as possible if it cannot be reliable through the posterior approach.

Terzis and Barmitsiotti published a large case series about their experience with axillary nerve reconstruction (n = 176). At 24-month follow-up, they reported well to excellent recovery in 45.95% of patients with the following concepts: intraplexus donors yielded significant better shoulder function than extraplexus donors, surgical intervention earlier than 4 months yielded significantly better functional outcomes more than that beyond 8 months, and patients whose root avulsions had a poor outcome [8]. Other studies were published about axillary nerve neurotization but using other donors rather than the radial nerve. Ray et al. [10] published a case series (n = 8) about axillary nerve neurotization but using the medial pectoral nerve as a donor with a success rate of 60% at a follow-up of 22.25 months. Jerome and Rajmohan [16] published a study about axillary nerve neurotization by using intercostal nerves with an anterior deltopectoral approach (n = 15), which revealed that all the involved patients had better recovery of external rotation at follow-up of 34.6 months. In 2022, Makel et al. [18] published a systematic review on the possible donor nerves for the SSN and axillary nerve reconstruction. They conducted a systematic search from 2001 to 2020 and involved 22 studies. Donor nerves investigated were radial nerve, intercostal nerves, medial pectoral nerve, ulnar nerve fascicle, median nerve fascicle, and lower subscapular nerve [18]. A total of 15 studies that investigated radial and intercostal nerves met the inclusion criteria for this meta-analysis [18]. They found no statistically significant difference between either of these nerves in the shoulder abduction strength according to the MRC score. Moreover, their findings support axillary nerve neurotization by the fascicle of the radial nerve when possible [18].

In this study, we performed neurotization of the axillary nerve by fascicle of the branch of the radial nerve of the medial head of triceps muscle, but we are unable to universalize our results and statistical analysis, as the number of the involved patients in this case series was relatively small.

Our study was limited in many aspects, including the limited number of patients that present within the proper time after the injury and the limited number of patients with available radial nerve (donor nerve) that was used in the procedure of nerve transfer surgery. We have to recommend an initiative to start a multicentric study with a higher number of patients who met the inclusion criteria. The ultimate goal is to reach a high level of evidence regarding guidelines to help surgeons choose the most appropriate surgical approach to different types of nerve injuries and clinical conditions.

**Conclusion**

When performing the technique of nerve transfer using the radial nerve (branch to the medial head of...
the triceps muscle) as a donor to innervate the axillary nerve (recipient nerve), it should be ensured that harvesting of the axillary nerve stump is proximal to the takeoff of the branch of the teres minor muscle, as it is the cardinal step for achieving the functional motor recovery by gaining shoulder abduction.

**Conflict of interest**

There are no conflicts of interest.

**Abbreviations list**

- **EMG** electromyography
- **MRC** motor research council
- **NCV** nerve conduction velocity

**References**


