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SURGERY ARTICLES

Medial pectoral nerve to axillary nerve neurotization following traumatic brachial plexus injuries: indications and clinical outcomes

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Abstract
Introduction The medial pectoral nerve (MPN) represents a viable donor nerve for neurotization procedures for restoration of shoulder function following upper trunk brachial plexus injuries.
Materials and Methods We report an eight-case series, single-surgeon experience of patients with upper trunk brachial plexus injuries who underwent MPN to axillary nerve (AXN) transfer from 2001–2007 for shoulder stability and abduction.
Results The mean patient age was 31.5 (range, 19–51 years). The mean follow-up for all patients was 22.25±7.4 months. Surgery was performed at a mean of 5.8±2.9 months post-injury. On initial evaluation, all eight patients had no deltoid function (M0). Of the eight patients examined postoperatively, we observed excellent recovery in four, good recovery in two, fair recovery in one, and poor functional recovery in the remaining patient.
Discussion MPN to AXN neurotization is a valid surgical option in the restoration of shoulder stability and shoulder abduction following trauma-related upper trunk brachial plexus injury.

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Introduction

For patients who have sustained a traumatic upper trunk brachial plexus injury, loss of shoulder and elbow function is due to root avulsions or injury to the suprascapular (SSN) and/or axillary nerves (AXN). For upper trunk injuries, primary reconstructive focus gives priority to shoulder stabilization with restoration of shoulder abduction and external rotation, as more distal functions are dependent on shoulder functionality and stability [22, 23].

The optimal treatment of brachial plexus injuries has rapidly evolved over the past several decades. Renewed focus on nerve transfer procedures has provided peripheral nerve surgeons with more reliable treatment options, along with improved patient outcomes. Utilizing a nerve transfer for the treatment of brachial plexus injuries is not a new concept [6, 11, 27], however an improved understanding of peripheral nerve biology, along with increasing clinical experience, has transformed the current treatment of complex brachial plexus injuries [2, 4, 15, 21, 26]. The medial pectoral nerve (MPN) can be surgically approached from either the infraclavicular route or from the supraclavicular approach at the level of the medial cord. Surgical accessibility, expendability, and a high number of motor fibers in the MPN make it an attractive donor nerve for upper plexus injuries.

Utilizing the MPN as a viable motor donor for brachial plexus injuries has been met with mixed reviews. Though no universal consensus exists, advocates have reported

favorable results for restoration of elbow flexion, shoulder abduction, and improved serratus anterior strength with transfer to the musculocutaneous nerve, axillary nerve, and long thoracic nerve, respectively, when using the medial pectoral nerve as a donor [8, 16, 18, 19, 25, 28]. In this case series, the authors report a single-surgeon series over 6 years in which the MPN–AXN neurotization was performed for the specific goal of restoration of shoulder motor function.

Materials and Methods

After obtaining institutional approval, a retrospective chart review of office and hospital charts was performed on all patients evaluated for brachial plexus injuries between May 2001 and June of 2007. Inclusion criteria admitted patients who had undergone medial pectoral nerve to axillary nerve transfer following traumatic brachial plexus injury with at least 10 months of follow-up.

Patient Population

This review included eight male patients. A summary of the cases is outlined in Table 1. All patients were initially evaluated at an outside hospital and subsequently referred to our institution for evaluation by the senior author. The resultant traumatic mechanisms of injury varied among patients. Several patients suffered additional systemic injuries at the time of brachial plexus injury due to the traumatic mechanism of injury including: closed head injury, clavicular fracture, distal radius fracture, and facial fractures.

All patients underwent preoperative clinical review, including detailed physical examination, pressure and grip strength testing, two-point discrimination, electromyography, and nerve conduction studies. Our clinical examination included testing all upper extremity musculature in comparison with the contralateral side, by the operating surgeon and physical therapist using the British Medical Research Council Grading System [5].

Brachial plexus exploration and reconstruction was performed using standard supraclavicular, infraclavicular, or combined approaches depending on the level of injury. Procedures requiring exposure of other major peripheral nerves were all performed concurrently with the initial operative procedure. Preoperative and postoperative assessments were made of both recipient and donor muscle groups.

Surgical Procedure

Exploration and reconstruction were undertaken if no clinical or documented electrical evidence of target muscle reinnervation was observed by 3 months post-injury. One exception was made for a patient who was involved in a motorcycle accident and who suffered severe avulsion injuries with no expectation for recovery, and thus underwent exploration 5 weeks post-accident.

Brachial plexus exploration was performed in standard fashion. An incision is made along the deltopectoral groove from the clavicle to the axilla and then continued distally to the medial aspect of the arm just proximal to the cubital fossa if a double fascicular transfer was also performed for elbow flexion. The entire brachial plexus and infraclavicular region is exposed identifying the middle, lateral, and posterior cords. The branches to the pectoralis major muscle are identified with intraoperative electrical stimulation and are used for transfer to the AXN (see Fig. 1). The pectoralis minor muscle was divided in order to identify the medial pectoral nerve branches. A disposable hand-held nerve stimulator (Vari-Stim®, Medtronic Xomed Inc, Jacksonville, FL) was used to "tap" along the under surface of the pectorals minor muscle. This allowed easy identification of the normally functioning medial pectoral nerves. The AXN is identified in the quadrangular space and followed proximally where it comes off of the posterior cord. In six cases, two to four fascicles of the MPN were directly coapted end-to-end to the axillary nerve allowing for proper size match. In two cases, the medial antebrachial cutaneous nerve was harvested as an interpositional graft between the MPN and AXN.

Spinal Accessory Nerve to SSN Was Performed in Three of Eight Cases

In five patients, redundant motor fascicles innervating the flexor carpi ulnaris (FCU) muscles were identified using selective sensorimotor electrical stimulation. The donor fascicle represented approximately 15–20% of the cross-section of the ulnar nerve. The FCU fascicle is then sutured directly to either the nerve to the biceps (three patients) or the nerve to the brachialis (two patients). Note that, before transfer of the FCU fascicle, sufficient remaining FCU innervation is verified with electrical stimulation of the main trunk ulnar nerve.

For five of eight patients, a detailed sensorimotor neurolysis of the median nerve was performed, identifying motor and sensory components. Redundant flexor digitorum sublimis fibers were transferred back to either the nerve to the biceps ($n=1$) or the nerve to the brachialis ($n=4$).

Postoperative management includes arm immobilization with the shoulder adducted, elbow flexed, and forearm in neutral. At 2–3 weeks, shoulder and elbow motion are gradually resumed to maintain range of motion. Occupational and physical therapies are undertaken in a focused

Table 1 Summary of the cases

DOS	Age/sex	Mechanism	Occupation	Time of injury to operation, months/weeks	Pre-op function	Operation	No. of fasicles	Post-op function	Follow-up period, months
2001	22/M	MVA, passenger	Student	4	Deltoid M0, L 18/100	MPN–MABC–AXN, neurolysis, AXN, PC, SSN,MCN, nerve graft to triceps/RT	4	Deltoid M 4-	10
2001	19/M	MVA, pedestrian	Student	5	Deltoid M0, L 24/110	MPN–AXN, neurolysis, MCN, MN, UN; FCU–BN, DS–BrN/Rt	4	Deltoid M 5-, L24/50	25
2001	26/M	30-ft fall	Laborer	10	Deltoid M0, L18/55	MPN–AXN; X1–SSN; DS+ FCU–BrN/Rt	3	Deltoid M 4, L 26/80	24
2001	25/M	Work-related/ throwing garbage	Laborer	9	Deltoid M0, L 18/100	MPN–AXN/Rt	3	Deltoid M 5, L21/85	20
2001	41/M	Cervical injury, cervical disc	Mechanic	4	Deltoid M0, L 20/80	MPN–AXN; XI–SSN/Rt	2	Deltoid M0 no shoulder function, L 24/95	23
2003	47/M	Racing boat accident	Machinist	7.5	Deltoid M0, L 24/70	MPN–AXN; XI–SSN; neurolysis MCN, MN, UN; DS–BN; FCU–BrN/Rt	3	Deltoid M 4, L30/65	17
2006	51/M	MVA, pedestrian	Student	6	Deltoid M0, L17/76	MPN–MABC–AXN; MPN–MABC–TN, DS–BrN, FCU–BN/Lt	3	Deltoid M 4-, L 6/46	36
2007	21/M	Motorcycle accident	Student	5	Deltoid M0, L18/82	MPN–AXN; DS–BrN; FCU-N; MABC–MN/Rt	2	Deltoid M 3, L 21/110	23

DOS date of surgery, *MPN* medial pectoral nerve, *AXN* axillary nerve, *XI* spinal accessory nerve, *SSN* suprascapular nerve, *PC* posterior cord, *MN* median nerve, *UN* ulnar nerve, *DS* digitor sublimis branch of median nerve, *FCU* flexor carpi ulnaris branch of ulnar nerve, *BN* biceps nerve, *BrN* brachialis nerve, *MABC* median antebrachial cutaneous nerve, *TN* triceps nerve, *MUP* motor unit potential, *MVA* motor vehicle accident

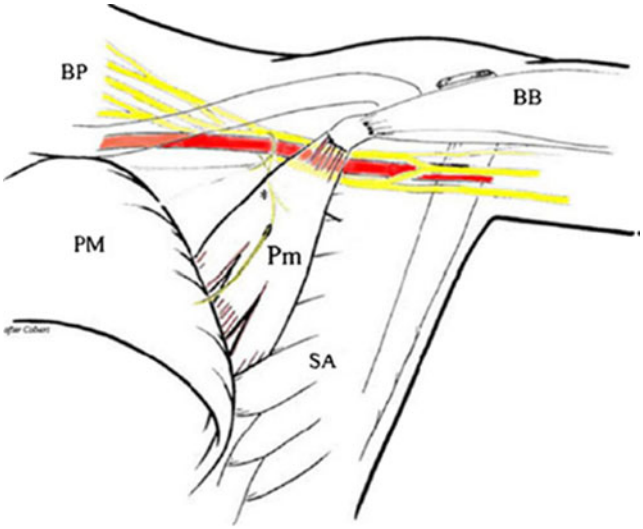

Fig. 1 Medial pectoral nerve and relevant anatomy. The medial pectoral nerves (denoted by *asterisk*) course deep of pectoralis minor (*Pm*), piercing the Pm to innervate the deep surface of pectoralis major (*PM*). Biceps brachii muscle (*BB*); brachial plexus (*BP*) roots; serratus anterior muscle (*SA*)

manner in the first postoperative year, often dictated by the patient's degree of recovery.

Results

All data are presented as mean±standard deviation. The mean patient age was 31.5 (range, 19–51 years). The mean follow-up for all patients was 22.25±7.4 months. Surgery was performed at a mean of 5.8±2.9 months post-injury. Postoperative functional assessment was graded according to the following scale to express outcomes: grades of M0–M2 indicated a poor result, M3 indicated a fair result, grade M4- indicated a good result, and grades M4- to M5 indicated excellent results. On initial evaluation, all eight patients had no deltoid function (M0). Of the eight patients examined postoperatively, we observed excellent recovery in four, good recovery in two, fair recovery in one, and poor functional recovery in the remaining patient. Six of eight patients had direct MPN–AXN neurotization, while two patients required interpositional grafts. The two patients receiving interpositional grafts (mean length of 14±1.4 cm) both had M4- deltoid recovery postoperatively.

Of the eight patients in this case series, four patients underwent early reconstruction, which is associated with a denervation time of less than 6 months (time from injury). Of these early reconstruction patients (n=4), one patient had excellent recovery in function, one had good recovery, one had fair recovery, and one had poor recovery. The other patients (n=4) underwent late reconstruction, which is defined as reconstruction at a time later than 6 months post-injury. Of these late reconstructive patients, one regained good (n=1) function and the remaining demonstrated excellent shoulder functional recovery (n= 3). Analyzing the data by age, half of these (n=4) patients undergoing reconstruction were less than 26 years of age. For the younger age group (<26 years), two patients demonstrated excellent results, one patient had good results, and one with fair results.

Of the patients older than 26 years old, two demonstrated excellent recovery, one with good results, and one with a poor functional outcome. During the primary brachial plexus surgery, additional nerve transfers for reconstruction of either shoulder or elbow function were performed in seven patients as described previously (Table 1 and "Materials and Methods"). Secondary procedures were performed on one patient who had multiple upper extremity tendon transfers for persistent radial nerve palsy. These procedures were performed 6 months after the initial brachial plexus reconstruction.

Discussion

Traumatic brachial plexus injuries represent a significant public health problem affecting more than 1% of multitrauma victims and nearly 5% of motorcycle accidents [14]. Traumatic brachial plexus injuries are devastating and often involve other serious systemic injuries. Thus, proper treatment of these patients often requires a multidisciplinary approach. Determination of appropriate management depends on both pre- and intraoperative nerve conduction studies, as well as the patient's individualized treatment goals. The use of nerve transfer procedures has become well established, providing peripheral nerve surgeons with multiple treatment options for proximal and intraplexus injuries. These approaches utilize both intraplexus and extraplexus motor donors such as the MPN. Other utilized nerves include the intercostals, thoracodorsal nerve, long thoracic nerve, phrenic nerve, distal accessory nerve, ipsilateral C7 root, contralateral C7 root, and the suprascapular nerve [3, 9, 13].

Additionally, the superiority of nerve transfers over tendon transfers in restoring shoulder function has become increasingly apparent. Nerve transfers do not alter the shoulder muscular biomechanics as tendon transfer do, allowing for greater potential for functional recovery [3].

Although well described in the literature, the utility of the MPN as a donor nerve remains controversial [17, 20, 28] due to the limitations in length, inappropriate diameter match, and potential loss of shoulder internal rotation. The MPN is a motor nerve derived from the medial cord of the brachial plexus, formed from the anterior division of the lower trunk [12, 18]. It is normal in upper plexus injuries. It

runs posterior to the axillary artery, joining with a branch of the lateral pectoral nerve anterior to the axillary artery forming a functional ansa pectoralis (loop). The MPN innervates the pectoralis major and both the sternal and costal heads of pectoralis minor. Three main spinal origin configurations exist for the MPN (see Fig. 2) [10]. However, 73% are composed of fibers from C8 and T1, alternatively C8 alone or T1 alone. As an intraplexus motor donor, the MPN has an increased number of donor motor axons. Its main trunk contains approximately 1,100 to 2,100 motor fibers [20]. Cadaver studies show a surgically obtainable length of up to 78 mm and a mean diameter ranging between 1.4 and 2.7 mm, with defined component spinal inputs from C8 and T1 [7, 10]. The sensory component of the axillary nerve is inferiorly located and the motor superiorly, so the donor grafts are preferentially directed to the superior portion of the axillary nerve. As an intraplexus donor, the MPN requires less postoperative re-education as the patients brain easily captures the various reconnections [24].

The MPN is a very easy nerve to "re-educate", perhaps because the input of the pectoral muscles comes from the entire brachial plexus. The utility of the MPN as a motor nerve donor has been well established in both pediatric and adult populations. In 1993, Brandt and Mackinnon et al. described the anatomical accessibility of the MPN and its role in functional recovery of the biceps muscle. A 25-case report series using the MPN as a motor donor to MCN and AXN demonstrated 85.7% functional recovery for MPN transfer to the MCN and 81.8% recovery for the AXN. Additionally, Wellons et al. reported an experience using the MPN as a donor nerve in the treatment of persistent birth-related brachial plexus palsies. Eighty percent of the reported patients showed enhanced functional recovery of elbow flexion in treated infants [29].

Others have transferred the MPN to the musculocutaneous nerve for repair of obstetric upper plexus injuries with excellent functional results [1]. Our institution has also demonstrated good results using the MPN as a donor nerve to augment elbow flexion [26]. As described previously, all patients that were treated using the MPN as a donor nerve had a functional lower plexus but required additional nerve transfers to optimize functional outcomes for the upper plexus injury. We have focused our case series here to evaluate MPN–AXN neurotization for shoulder functional restoration, with modification of shoulder abduction and external rotation. Out of the eight cases presented, 75% experienced either good or excellent return of shoulder function following MPN–AXN neurotization, proving the utility of this procedure for restoring shoulder function post-traumatic injury. The majority of our cases (n=6) were direct MPN–AXN neurotization, as this is the preferable route. However, our results indicate that interpositional grafts may be also used and lead to good shoulder functional outcomes. Although we hypothesized that younger patients would have improved functional outcomes, we did not observe any differences among the two different age groups. In addition to this hypothesis, we also expected to see a generalized trend towards improved outcome in patients who underwent surgery sooner (less than 6 months post-injury) than later, and patients having direct MPN–AXN neurotization. However, we were not

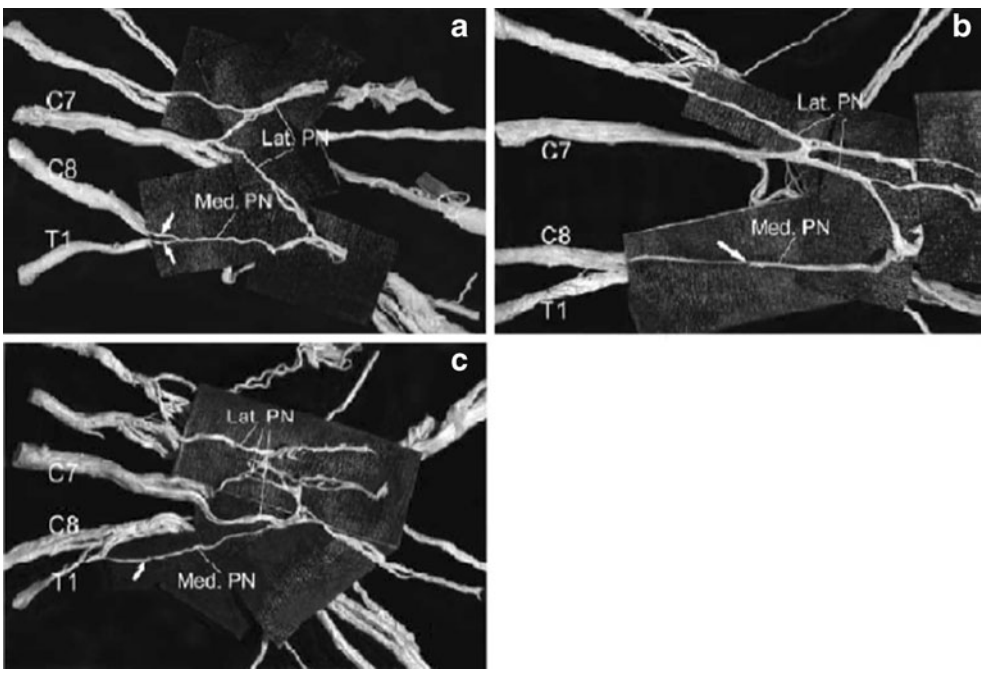

Fig. 2 Spinal origin variation of medial pectoral nerve. Anatomic variation of lateral and medial pectoral nerves. The MPN was formed by C8 and T1 (**a**) in 73.3% of cases, by C8 (**b**) in 23.4% of cases, and by T1 (**c**) in 3.3% of cases. *Arrows* denote each spinal nerve participating in the MPN. Reprinted from Lee [10]

able to do a formal statistical analysis in these parameters as the patient enrollment in this case series was relatively small (n=8).

We have been impressed with the use of the posterior approach for a double transfer of the distal accessory to the suprascapular nerve and the medial triceps to the axillary nerve [3]. Our indications for the use of MPN–AXN neurotization include the following: (1) functionally intact lower trunk (C8–T1) uninvolved in traumatic injury; (2) detailed anatomic understanding and sophisticated surgical technique to isolate and transfer MPN branches to the AXN. (3) We emphasize dissection of the recipient axillary nerve as proximal as possible in the quadrangular space so as to include the nerve to teres minor. We became aware of the importance of including the teres minor branch when our first posterior triceps to axillary nerve transfer that did not specifically include the teres minor nerve was noted to be inferior to our anterior approach to the axillary nerve with the MPN to axillary nerve transfer. We will now use the posterior approach to the axillary nerve for a medial triceps to axillary nerve and utilize the MPN to axillary nerve when an anterior approach is more applicable.

Terzis et al. published a large case series of their experience with SSN reconstruction, wherein the authors discuss current limitations of comparing postoperative results of brachial plexus injury reconstruction [23]. We agree that there needs to be standardized, validated, and globally accepted evaluation system for postoperative results in order to adequately recommend specific surgical interventions and to advance the field of plexus surgery as a whole.

Conclusion

MPN to AXN neurotization is a valid surgical option in the restoration of shoulder stability and shoulder abduction following trauma-related upper trunk brachial plexus injury. It is an attractive option as a donor for brachial plexus injuries because of its accessibility and relatively high number of donor motor neurons. In fact, we have used the MPN not only for transfer to the axillary and musculocutaneous nerve transfers, but also for the suprascapular and accessory nerves. The authors acknowledge that the use of the MPN is not always feasible due to pattern of injury (i.e., middle trunk injury), yet this nerve should not be overlooked when treating a patient with a brachial plexus injury involving the superior trunk.

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