Case Report

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Nerve Transfers to the Musculocutaneous and Suprascapular Nerve for Restoration of Elbow and Shoulder Function in Brachial Plexus Avulsion: An Early Experience

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The diagnosis of brachial plexus avulsion is often delayed by concomitant trauma to the arm and shoulder. Therefore, nerve transfer surgery to restore elbow and shoulder function is rarely reported. We present our initial experience of double fascicular nerve transfer for upper brachial plexus avulsion. A 26-year-old male patient presented with a 5-month history of unresolving pain and paralysis involving his left shoulder and elbow following a motorcycle accident. Avulsion of the C5 and C6 ventral roots and C6 dorsal root was confirmed by a myelographic computed tomography scan. After lesioning of the dorsal root entry zone due to painful avulsion, double fascicles (flexor carpi radialis and flexor carpi ulnaris) of the median and ulnar nerve) were transferred to the biceps brachii and brachialis branches of the musculocutaneous nerve to restore elbow flexion. Two weeks after the first transfer surgery, the distal accessory nerve was transferred to the suprascapular nerve to ensure shoulder function. Six months after the nerve transfers, elbow flexion recovered to Medical Research Council grade 3, but shoulder function did not show any improvement. An additional nerve transfer (triceps branch of the radial nerve to the axillary nerve) was planned for shoulder function. It is necessary to refine the microsurgical suture technique. For shoulder function, it is recommended to perform radial nerve transfer at the time of the first surgery.

Keywords: Brachial plexus; Musculocutaneous nerve; Nerve transfer; Radiculopathy

INTRODUCTION

Loss of shoulder and elbow function is typical of upper brachial plexus avulsion[3,13]. Motor root avulsion of the C5 and C6 roots results in Erb palsy, with loss of supply to muscles innervated by the suprascapular nerve, axillary nerve, and musculocutaneous nerve[3]. In the case of root avulsion, the absence of proximal nerve stump prevents nerve graft reconstruction and no spontaneous recovery of the shoulder and elbow function is anticipated[13]. Therefore, nerve transfer should be considered for restoration of the elbow and shoulder function. In 1994, Oberlin et al.[8] reported the technique of nerve transfer from a redundant fascicle of the ulnar nerve to the biceps brachii branch of the musculocutaneous nerve for restoration of elbow function due to upper brachial plexus avulsion. However, the importance of the brachial muscle in elbow flexion was subsequently confirmed and the technique for the transfer of double fascicular nerves to both the biceps brachii and brachialis muscles was introduced[7]. The so-called ‘double fascicular nerve transfer’ entails a surgical transfer of the flexor carpi radialis (FCR) and flexor carpi ulnar (FCU) branches of the median and ulnar nerves to the biceps brachii and brachialis branches of the musculocutaneous nerve for functional restoration of elbow flexion[2-4,6,7,12-15]. It yielded better results than the technique reported by Oberlin et al.[8] for upper brachial plexus avulsion[7].

Brachial plexus avulsion causes characteristic pain and paralysis in the upper extremities but often goes undiagnosed for years due to trauma to the shoulder and arm[5,9,10]. Despite pain surgery for neuropathic pain in brachial plexus avulsion[5,9,10], no surgical restoration of the function of the elbow and shoulder was possible because it was referred to the authors one year after a shoulder injury. Finally, the authors had an opportunity to identify and treat brachial plexus avulsion in a patient who presented with pain and paralysis in the left arm within 1 year of the injury. We would like to report our initial experience with nerve transfer surgery. Even though the diagnosis of avulsion was delayed by more than 5 months, motor nerve transfer was still possible. We hope the challenges and efforts due to our lack of experience will educate our colleagues performing nerve transfer.

CASE REPORT

A 26-year-old male patient presented with numbness and pain in the left arm and paralysis of the left shoulder and elbow after a motorcycle accident (Fig. 1A). The patient was first taken to the emergency room of our hospital and diagnosed with a blow-out fracture of the left orbit, a deep laceration of the left forearm, and multiple contusions. He was transferred to a hospital for inpatient treatment. Reduction and internal fixation for the left blow-out fracture was performed 2 weeks after the injury. The patient believed that wearing a cast for lacerations and contusions on his left arm would eventually alleviate the pain and weakness in his left arm. Unfortunately, even his medical staff were not aware of his left arm paralysis. In the absence of any improvement in pain and numbness in his left arm two months after the injury, an magnetic resonance imaging (MRI) of the cervical spine was performed. A cervical cord abnormality was suspected on the MRI and a referral was made to the spine division of the neurosurgical department at the author’s hospital. However, the spine surgeon ruled out any cervical spine defect and referred the patient to the authors. It took him four months to interview the senior author.

On physical examination, extension of the left shoulder as possible, but only up to 30 degrees of flexion (Fig. 1B). Internal and external rotation of the left shoulder was impossible. The left elbow also allowed some extension but no flexion at all (Medical Research Council [MRC] grade 0) (Fig. 1B). Mild weakness was observed in wrist extension, flexion and abduction of the fingers, and thumb opposition (MRC grade 4). Moderate hypesthesia was observed on the lateral side of his left upper arm, on the radial side of the forearm, on the hand dorsally, and in the first and second fingers. In particular, severe numbness and pain were observed in the left forearm and the first and second fingers (Fig. 1A). The pain was characterized by persistent numbness with intermittent electric shock in the area of hypesthesia. Allodynia was not observed.

Atrophy of the supraspinatus and infraspinatus and deltoid muscles of the left shoulder as well as atrophy of the left biceps brachii were observed (Fig. 1B). Mild atrophy was also observed in the intrinsic muscles of the left hand. No deep tendon reflex of the biceps brachii was elicited. A simple radiographic examination of the cervical spine showed no abnormal findings such as fractures. In the myelographic computed tomographic (CT) scan of the cervical spine, the anterior and posterior roots of the C5 and C6 spinal cord were absent; however, no pseudomeningocele was observed (Fig. 1C). The characteristic pain pattern and paralysis associated with the absence of the roots in the myelographic CT scan of the cervical spine led to the diagnosis of brachial plexus avulsion. Recognizing that pain and paralysis of brachial plexus avulsion were unlikely to improve, dorsal root entry zone (DREZ) lesioning and nerve transfer surgeries were planned. One week after confirming improvement of the left arm pain (reduced from 6/10 to 2/10 on numeric rating scale-11) and absence of neurological abnormality with microsurgical DREZ lesioning (Fig. 1D), a double fascicular nerve transfer to improve the function of his left elbow was planned as suggested by Mackinnon et al.[7].

After making an incision of about 20 cm in the upper arm

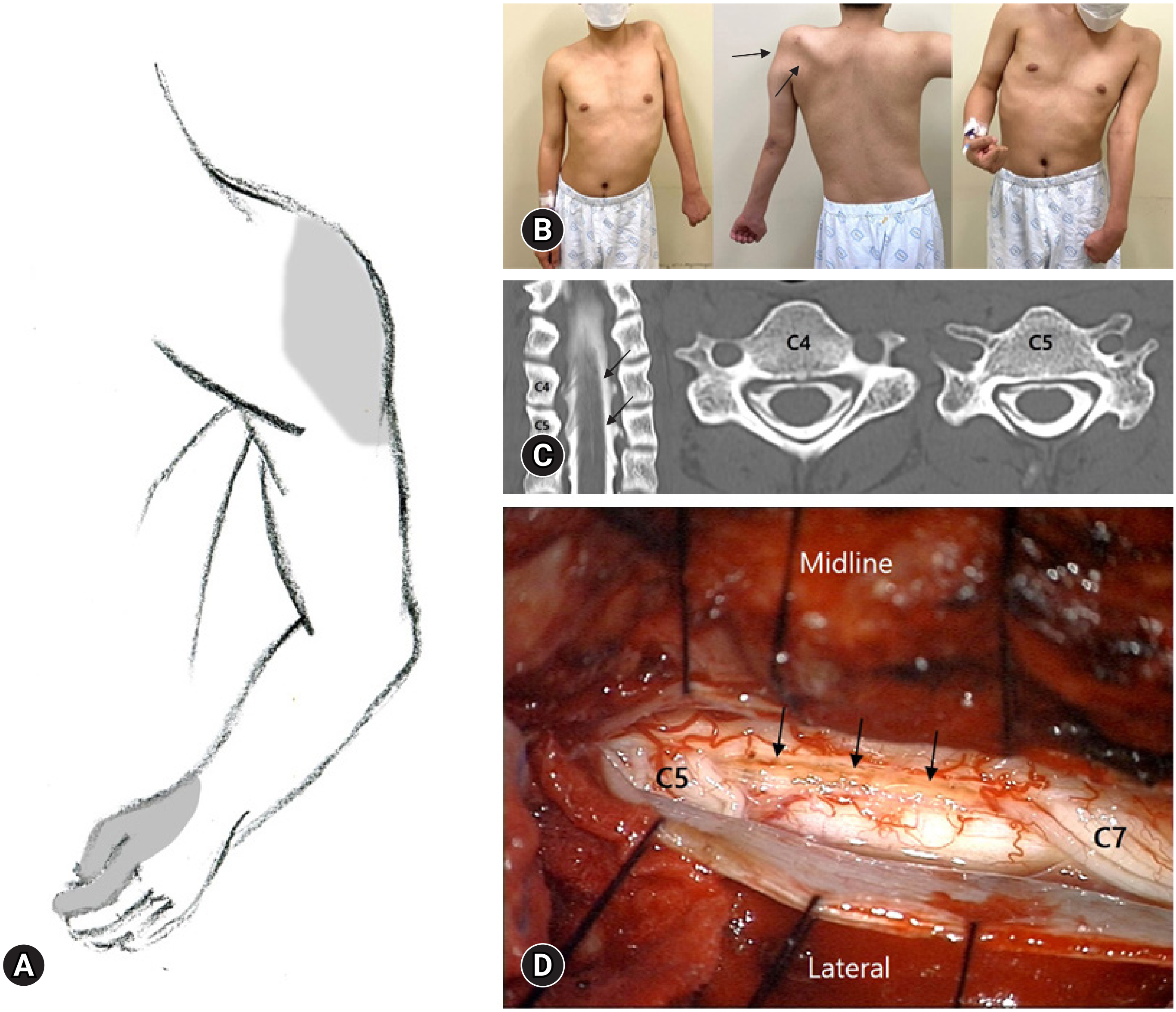

Fig. 1. Distribution of pain in brachial plexus avulsion and weakness and atrophy of the left shoulder and arm. (A) Schematic representation of the distribution of pain due to upper (C5–6) brachial plexus avulsion. Gray areas indicate the location of continuous severe paresthesia superimposed on stabbing pain during the onset of trauma (gray area). (B) Clinical photographs showing an absence of shoulder abduction (left and middle images). Severe atrophy was observed in the deltoid and infraspinatus muscles (arrows). There was no flexion of the right elbow (right). (C) Coronal and axial myelographic computed tomography images showing avulsion of the cervical roots. A coronal image (left) shows no travel of the left C5 and C6 ventral roots. At the level of C4, the left ventral root is not observed. At the C5 level, neither the left ventral nor the dorsal root is observed (middle and right images). (D) An intraoperative photograph showing the absence of the dorsal C6 rootlets due to avulsion. The dorsal rootlets of the C5 and C7 were preserved. Microsurgical dorsal root entry zone lesioning was performed (arrows) in the avulsed posterolateral sulcus.

of the left arm, the biceps and brachialis muscles were identified, the path of the musculocutaneous nerve, the branches to the biceps and brachialis muscles, and the lateral antebrachial cutaneous nerve were identified and neurolyzed (Fig. 2A, B). Subsequently, among expandable or redundant segments (FCR/palmaris longus [PL], flexor digitorum superficialis [FDS] component) of the median nerve (MN), the FCR/PL branch was addressed using topographic anatomy

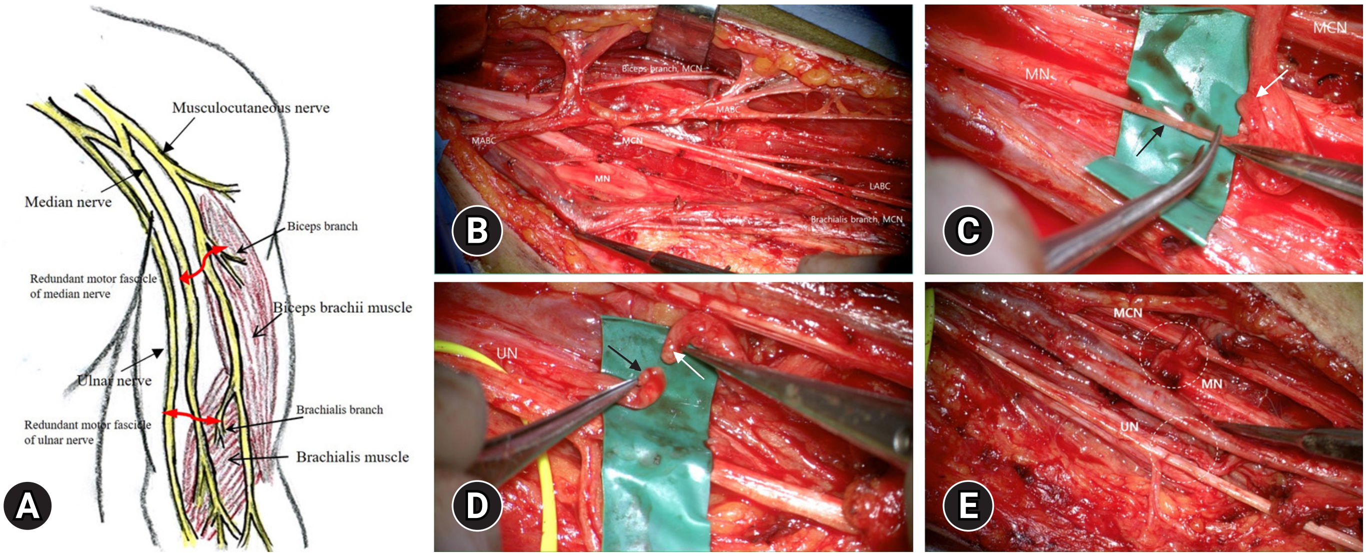

Fig. 2. Double fascicular nerve transfer for restoration of elbow function. (A) A schematic diagram showing the procedure of double fascicular nerve transfer. (B) An intraoperative photograph showing initial exposure of the branches of the musculocutaneous nerve (MCN) and median nerve (MN). (C) The redundant flexor carpi radialis fascicle (black arrow) was internally neurolyzed and cut. The mobilized, cut end of the biceps branch (white arrow) of the MCN enabled tension-free, end-to-end anastomosis. (D) Approximation of the cut edge of the brachialis branch (white arrow) of the MN and the flexor carpi ulnaris fascicle (black arrow) of the ulnar nerve (UN). (E) An intraoperative photograph showing double fascicular nerve transfer in the upper arm. Two anastomotic sites (white circles) are noted. LABC, lateral antebrachial cutaneous nerve of the musculocutaneous nerve; MABC, medial antebrachial cutaneous nerve.

and intraoperative nerve stimulation (monopolar stimulation, 12 Hz, 0.5-1 mA). The redundant FCR branch was dissected from the MN (Fig. 2C). During internal neurolysis of the MN, the critical pronator and anterior interosseus branches were preserved via intraoperative stimulation. Then, the FCU fascicle of the ulnar nerve was identified via nerve stimulation (Fig 2D) and internal neurolysis was performed. Sufficient length of the donor nerve was ensured to prevent tension during end-to-end anastomosis. End-to-end coaptation was performed using 9-0 nylon (the FCR fascicle to the biceps branch, and the FCU branch to the brachialis branch) and a fibrin sealant (Beriplast P Combi-Set; CSL Behring Pharma, Tokyo, Japan) was applied to the repair site (Fig. 2E). The left arm was immobilized in a sling for 7 days. Three weeks later, transfer of the distal accessory nerve to the suprascapular nerve was performed via the posterior approach.

A transverse incision 10 cm in length and 2 cm above the scapular spine was made. After elevation of the trapezius muscle, the distal accessory nerve was dissected and mobilized, and then divided distally (Fig. 3A). At the suprascapular notch, the suprascapular ligament was divided to expose the suprascapular nerve (Fig. 3B). The suprascapular nerve was mobilized and transected proximally to provide adequate nerve length to transpose superficially toward the distal accessory nerve. The direct repair was performed between the distal end of the distal accessory nerve and the proximal part of the suprascapular nerve (Fig. 3C).

No sensorimotor complication associated with nerve transfer surgery was detected. The first signs of reinnervation were seen 3 weeks after surgery. The patient showed minimal elbow flexion without resistance to gravity (MRC grade 2). However, shoulder abduction and extension did not improve. Elbow flexion improved 6 months to a full range of motion against gravity (MRC grade 3) (Fig. 4). However, clinical recovery of shoulder function was not seen 6 months after the nerve transfer. Since there were only two months left for reinnervation after injury, and clinical recovery of shoulder function was not observed even after 6 months of nerve transfer, transfer of medial triceps branch of the radial nerve to axillary nerve was planned for shoulder function.

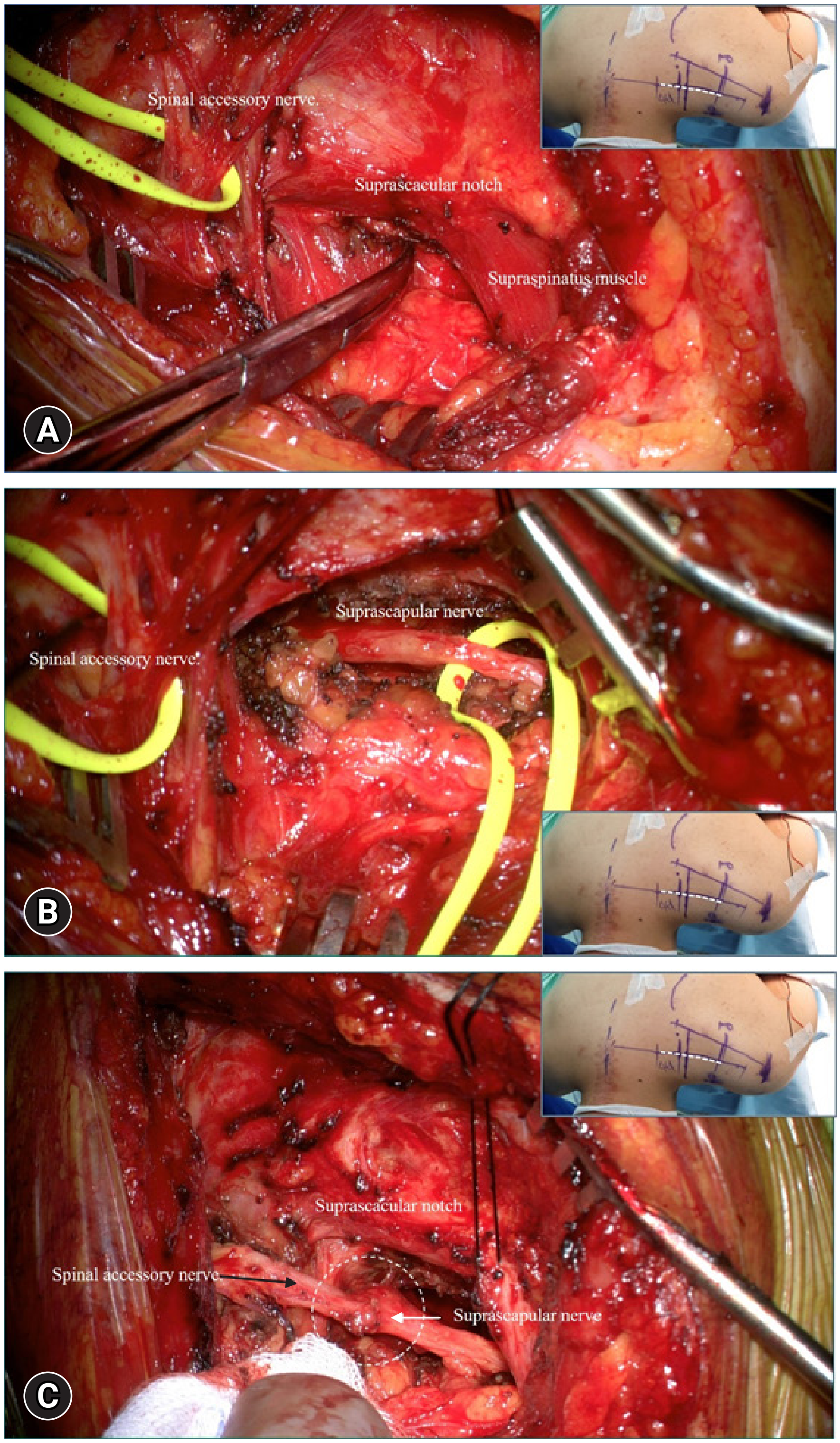

Fig. 3. Posterior approach to nerve transfer of the distal accessory to the suprascapular nerve for shoulder function. (A) An intraoperative photograph showing the exposure of the suprascapular notch via posterior approach. The spinal accessory nerve was identified with elevation of the trapezius muscle and intraoperative stimulation. The inset shows the incision location for the posterior approach. (B) Isolation of the suprascapular nerve after division of the suprascapular ligament at the suprascapular notch. (C) An intraoperative photograph showing end-to-end coaptation of the cut edges of the distal accessory and suprascapular nerves.

Fig. 4. Clinical images showing the results of the nerve transfers at postoperative 6 months. The patient's left elbow flexion improved to facilitate full range of motion (Medical Research Council grade 3). However, shoulder abduction improved only slightly.

DISCUSSION

Nerve transfer instead of nerve graft

In the case of brachial plexus avulsion, the absence of or inaccessible proximal nerve stump may not allow graft reconstruction. Therefore, motor nerve transfer is the only reconstructive option available[13)]. Nerve transfers have been used with increasing frequency for the reconstruction of proximal upper extremity nerves and brachial plexus injuries[6)].

Nerve transfer is associated with multiple advantages. It allows dissection in uninjured and unscarred tissue planes and minimizes the regeneration time and distance. Optimal muscle reinnervation depends on sufficient number of regenerating motor axons reaching their target neuromuscular junctions within approximately 1 year following the injury[8)]. Consequently, the outcomes after proximal nerve repair or reconstruction with grafts are frequently poor because of the irreversible loss of the target motor end plates with degeneration and fibrosis[13)]. Selection of motor nerve in close proximity to the target muscle minimizes the regeneration distance and time for muscle reinnervation prior to permanent motor end plate loss[13)].

The choice of optimal donor nerve is based on factors such as the number of motor axons, location near the target muscle, and synergy of muscle function. Nerve branches that innervate muscle alone or motor fascicles that can be readily neurolyzed from a mixed nerve, such as the FCU fascicle of the ulnar nerve, are preferred donor nerves[4,12,13)]. The use of donor nerves that innervate expandable muscles has a synergistic effect on the target muscle and facilitates postoperative rehabilitation and motor re-education with increased likelihood of a successful outcome[13)].

Nerve transfers for elbow function

Functional reconstruction following a complete brachial plexus injury is focused initially on restoration of elbow flexion, followed by shoulder abduction. Selection of the donor nerve with the largest caliber and the greatest number of motor axons is recommended[13)]. Many options for nerve transfer exist for the restoration of elbow flexion, and the most appropriate option depends largely on the availability of donor motor nerve[6,7)]. Suggested donor nerves include redundant FCU fascicle of the ulnar nerve, redundant FCR or PL fascicle of the MN, FDS, medial pectoral nerves, thoracodorsal nerves, distal spinal accessory nerves, and intercostal nerves[13)].

Oberlin et al.[8] first introduced the FCU-to-biceps transfer for reinnervation of the biceps muscle in C5 and C6 brachial plexus avulsion by transferring the redundant FCU fascicle from the ulnar nerve to the biceps branch of the musculocutaneous nerve. In a follow-up series of 32 patients reported in 2004, an elbow flexion of MRC grades 3 to 4 was achieved in 94% of cases[7]. No significant donor morbidity was seen[7]. However, 10 patients required a Steiner flexorplasty to obtain satisfactory elbow flexion[7,8]. To achieve further successful elbow flexion, the importance of reinnervation of the brachialis muscle was suggested[7,14]. The brachialis muscle is a stronger elbow flexor than the biceps muscle and its reinnervation was performed with the medial pectoral and thoracodorsal nerve branches in addition to the FCU transfer to the biceps[7]. Initial results of brachialis muscle reinnervation were better than the procedure suggested by Oberlin et al.[8] strong elbow flexion of MRC grade 4 or better was obtained and no patient required additional tendon transfer surgery[7]. The brachialis muscle is the primary elbow flexor, while the biceps muscle is a primary forearm supinator and secondarily provides elbow flexion, reinnervation of the brachialis muscle in addition to strengthening elbow flexion[2].

Recognizing the superior functional outcome with reinnervation of the brachialis muscle, Mackinnon et al.[7] suggested double fascicular nerve transfer from the median (FCR/PL fascicle) and ulnar (FCU fascicle) nerves to the biceps and brachialis branches of the musculocutaneous nerve[15]. In the current case, avulsion of the ventral root occurred in C5 and C6, and in upper brachial plexus avulsion, the motor function of the median and ulnar nerves was preserved. Therefore, we adopted the technique of double fascicular nerve transfer recommended by Mackinnon et al.[3,7,13].

If the motor function of the median and ulnar nerves is not preserved in case of complete brachial plexus avulsion, medial pectoral and thoracodorsal nerves are suggested as alternative donor nerves for nerve transfer[7,13,14]. In case of a complete brachial plexus injury, the distal accessory and intercostal nerves are the another alternative[13]. The distal accessory nerve requires a long nerve graft and is generally reserved for transfer to the suprascapular nerve for shoulder function[13]. The intercostal nerves are small, and although direct transfer to the proximal musculocutaneous nerve in the axilla is feasible, the regeneration distance is long[13]. Less favorable options include the contralateral partial C7 root and the phrenic nerve.1 However, their use is still limited.

Nerve transfer for shoulder function

In case of brachial plexus avulsion, shoulder abduction is the next priority, which entails reinnervation of the supraspinatus and infraspinatus muscles and deltoid[13]. The distal accessory nerve has been recommended as a standard transfer to the suprascapular nerve, which innervates the supraspinatus and infraspinatus muscles. It is readily available and the trapezius muscle provides a synergistic function[13]. We selected the posterior approach for distal accessory nerve transfer. The advantages of the posterior approach for distal accessory nerve transfer are well known. It facilitates release at the suprascapular notch, preserves further innervation of the trapezius, provides a wider exposure for the nerve transfer, and allows a more distal transfer to minimize the regeneration time and distance[11,13]. If the need for a long nerve graft is certain, one or both sural nerves can be harvested simultaneously when prone[13]. The anterior approach to the accessory and suprascapular nerves is also regarded as a robust method for nerve transfer. As other donor nerves, the medial pectoral and the thoracic nerves may also be considered.

Splitting the scapular ligament at the scapular notch to secure the scapular nerve in the posterior approach was unfamiliar to us given our limited experience. However, the anatomical landmarks proposed by some authors[13] and careful microscopic dissection facilitated dissection of the proximal scapular nerve as far as possible and mobilization of sufficient length for superficial dislocation toward the distal accessory nerve[13]. The distal accessory nerve is located 44% medial to the midpoint of a line drawn from the thoracic spine to the angle of the acromion of the shoulder (Fig. 3)[13].

Limitations

Due to the short follow-up period of 6 months, the authors fail to obtain good results with MRC grade 4 or higher in this case. Additional nerve transfer from the medial triceps branch of the radial nerve to the axillary nerve is currently planned for shoulder function with no visible improvement. We admit that despite performing theoretically rational nerve transfers based on suggestions of experienced authors[3,4,6-8,12-14], we have yet to achieve good results. We considered our limitation of experience with epineurium repair as one of the possible reasons for the poor outcome. We note the possibility that microsurgical epineurial repair techniques may not have been perfect. In the absence of confirmed clinical effects of nerve transfer, re-anastomosis may be considered. The primary goal is to achieve motor axon reaching the target muscle end plate prior to muscle fibrosis and atrophy, which occurs at 12 months[7,8]. Functional recovery is proportional to the number of axons reaching the target end plate and inversely proportional to the time of denervation[12,13].

It was suggested that the decision regarding appropriate donor/recipient nerve configuration is based on the best tension-free orientation[13]. However, configuration of the FCR branch of the median to brachialis branch and the FCU branch of the ulnar to the biceps branch was favored[13]. Since motor re-education is more synergistic as the MN is associated with pronation and the biceps with supination[6,13]. We anastomosed the FCU bundle of the ulnar nerve to the brachialis branch, which might affect delayed responses. In fact, the nerve transfer from the medial triceps branch of the radial nerve to the axillary nerve is currently scheduled for shoulder function that does not show improvement even after 6 months after surgery. Nerve transfer of the radial nerve to the axillary nerve is more effective when performed together with the distal accessory nerve transfer to the suprascapular nerve[1,11]. Since we are still inexperienced, we could not perform two nerve transfers during the first operation. We anticipate improvement of shoulder function via additional nerve transfer and would like to report longer-term results in the future. Although excellent results were not reported, we hope that the authors' early experiences will enable our colleagues who treat patients diagnosed with the same disease in the future.

CONCLUSION

Upper brachial plexus avulsion injuries involving C5 and C6 are the most common root avulsion injuries. Because it is a preganglionic injury, no feasible proximal nerve reconstruction procedure exists. Other options for the restoration of elbow and shoulder function include arthrodesis, which sacrifices motion and tendon transfer with suboptimal results. Recent developments in nerve transfer techniques yielded better results compared with traditional reconstructive procedures. Nerve transfers provide earlier reinnervation to the target muscles due to anatomic proximity compared with procedures performed at the root level.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

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