Nerve transfers to the biceps and brachialis branches to improve elbow flexion strength after brachial plexus injuries

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Object. In this study the authors evaluated the outcome in patients with brachial plexus injuries who underwent nerve transfers to the biceps and the brachialis branches of the musculocutaneous nerve.

Methods. The charts of eight patients who underwent an ulnar nerve fascicle transfer to the biceps branch of the musculocutaneous nerve and a separate transfer to the brachialis branch were retrospectively reviewed. Outcome was assessed using the Medical Research Council (MRC) grade to classify elbow flexion strength in conjunction with electromyography (EMG).

The mean patient age was 26.4 years (range 16–45 years) and the mean time from injury to surgery was 3.8 months (range 2.5–7.5 months). Recovery of elbow flexion was MRC Grade 4 in five patients, and Grade 4+ in three. Reinnervation of both the biceps and brachialis muscles was confirmed on EMG studies. Ulnar nerve function was not downgraded in any patient.

Conclusions. The use of nerve transfers to reinnervate the biceps and brachialis muscle provides excellent elbow flexion strength in patients with brachial plexus nerve injuries.

KEY WORDS • brachial plexus • nerve transplantation • Oberlin procedure

Nerve transfers are commonly used in the reconstruction of brachial plexus injuries when root avulsion has occurred or when the lesion is very proximal. Many techniques and donor nerves have been described, and the most appropriate choice depends on the level of the lesion and the availability of donor motor nerves. In 1994, Oberlin, et al., reported the transfer of a redundant FCU fascicle from the functioning ulnar nerve directly to the biceps branch of the musculocutaneous nerve to restore elbow flexion. Their original description consisted of a series of four patients and a cadaveric study of the branching pattern of the musculocutaneous nerve to the biceps muscle. In 1997, this was followed by a clinical series of 18 patients. Good elbow flexion with MRC Grade 3 to 4 muscle strength was obtained in most cases, but five patients required an additional Steindler flexorplasty to achieve satisfactory elbow flexion.

The restoration of elbow flexion by nerve transfer has generally focused on reinnervation of the biceps muscle, which acts as a primary forearm supinator and secondarily provides elbow flexion. The brachialis is the primary muscle providing elbow flexion; therefore, reinnervation of both the biceps and brachialis muscles should maximize the potential for recovery of strong elbow flexion. The purpose of this study was to evaluate recovery of elbow flexion after the Oberlin procedure, which consisted of ulnar nerve fascicle transfer to the biceps branch of the musculocutaneous nerve, augmented by a nerve transfer to its brachialis branch.

Clinical Material and Methods

After approval by our institution’s Human Studies Committee, a retrospective chart review was performed. Inclusion criteria admitted patients with a brachial plexus injury who had undergone a nerve transfer between 1997 and 2000 in which redundant ulnar nerve fascicles of the FCU were attached to the biceps branch of the musculocutaneous nerve, in addition to a similar transfer to reinnervate the brachialis muscle.

Patient Population

The study sample consisted of eight men (Table 1). All patients were initially seen and treated at outlying hospitals and then referred for repair of the brachial plexus injury. Their mean age was 26.4 ± 10 years (± SD, range 16–45 years). The injury involved the dominant upper extremity in three patients and the nondominant arm in five. The mechanism of injury was a motor vehicle accident in four patients, a motorcycle accident in two, and two patients expe-
reinnervated a direct blow to the head or shoulder. At the initial evaluation, four patients received a diagnosis of C5–6 brachial plexus nerve injury, and in the other four patients a complete brachial plexus injury was identified. In the latter group, recovery of the lower plexus permitted consideration of the Oberlin transfer procedure. Significant accompanying injuries included closed head injury, basilar skull fracture, clavicular fractures, rib fractures, and intraabdominal injuries. Six patients were employed full time when they were injured, and the other two were full-time students.

Surgical Procedure

Reconstruction was undertaken if no clinical or electrical evidence of biceps muscle function was seen by 3 months postinjury. Surgery was performed a mean of 3.8 ± 1.6 months postinjury (± SD, range 2.5–7.5 months).

Brachial plexus exploration was performed using a standard infraclavicular exposure, which extended from the clavicle along the deltopectoral groove to the axilla, and then continued distally to the elbow along the brachial sulcus on the medial aspect of the upper arm.15,16 The insertions of the pectoralis major and minor muscles were reflected and the pectoralis major muscle was retracted medially to expose the brachial plexus and the medial pectoral nerve branches. The major peripheral nerves in the upper arm were identified and dissected (including the ulnar and median nerves), as were the musculocutaneous nerve and its branches to the biceps and brachialis muscles.

For the Oberlin transfer, a segment of ulnar nerve adjacent to the biceps branch was mobilized and dissected into approximately five fascicles by using internal neurolysis (Fig. 1). Redundant motor fascicles supplying the FCU were identified using direct electrical stimulation (Medtronic, Jacksonville, FL), and one fascicle was selected for transfer. The donor fascicle was usually 20% of the ulnar nerve, and sufficient residual FCU innervation was verified using electrical stimulation of the main ulnar nerve before transfer; all patients underwent an Oberlin procedure.

For transfer to the brachialis branch of the musculocutaneous nerve in six of eight patients, neurolysis of the LABC nerve was performed separately from neurolysis of the branch to the brachialis muscle in the distal upper arm to permit transfer of just the motor components of the musculocutaneous nerve. In the other two patients, the donor motor nerve used to reinnervate the brachialis was transferred to the musculocutaneous nerve distal to the biceps branch (brachialis and LABC components). The LABC nerve was then transposed proximally into the biceps muscle near the motor endplate in one case, and in the other the LABC nerve was used to reinnervate other forearm muscles.

Four different nerve donors were used for transfer to the brachialis branch of the musculocutaneous nerve: the medial pectoral, intercostal, and thoracodorsal nerves, along with a triceps branch of the radial nerve (Table 1). In five cases, branches of the medial pectoral nerve were transferred to the brachialis branch of the musculocutaneous nerve with a graft (Table 1). In five cases, branches of the medial pectoral nerve were identified with direct electrical stimulation and dissected from beneath the minor and major pectoral muscles. In one patient, a medial pectoral branch and two intercostal motor nerves were transferred using a graft to the brachialis branch of the musculocutaneous nerve. In the other two cases, the thoracodorsal nerve and a triceps branch of the radial nerve were used to reinnervate the brachialis branch of the musculocutaneous nerve, and a direct nerve-to-nerve coaptation was performed. The thoracodorsal nerve was harvested through a separate vertical chest incision along the anterolateral border of the latissimus dorsi muscle.

The MABC nerve was used as a donor nerve graft in four cases, with a mean length of 12 ± 3.8 cm (± SD, range 6.5–15 cm), and the LABC nerve was used in one case (16.5-cm nerve graft). In one patient, both the MABC (12 cm) and LABC (8 cm) nerves were harvested for grafts (Table 1).

Postoperative management included shoulder immobilization in adduction, internal rotation, and elbow flexion for

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**TABLE 1**

Nerve transfer to the brachialis muscle

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Donor Nerve</th>
<th>Nerve Graft</th>
<th>Graft Length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>medial pectoral</td>
<td>MABC</td>
<td>15.0</td>
</tr>
<tr>
<td>2</td>
<td>medial pectoral</td>
<td>MABC</td>
<td>6.5</td>
</tr>
<tr>
<td>3</td>
<td>medial pectoral</td>
<td>MABC</td>
<td>12.0</td>
</tr>
<tr>
<td>4</td>
<td>medial pectoral</td>
<td>MABC</td>
<td>14.0</td>
</tr>
<tr>
<td>5</td>
<td>medial pectoral</td>
<td>LABC</td>
<td>16.5</td>
</tr>
<tr>
<td>6</td>
<td>medial pectoral,</td>
<td>LABC</td>
<td>8.0</td>
</tr>
<tr>
<td>7</td>
<td>intercostal</td>
<td>MABC</td>
<td>12.0</td>
</tr>
<tr>
<td>8</td>
<td>thoracodorsal</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>9</td>
<td>triceps branch</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

* Reinnervation of the biceps muscle was also performed in all patients by using a redundant FCU fascicle of the ulnar nerve. — = none needed.
1 month to allow healing of the major pectoral muscle/tendon insertion. Range of motion exercises for the elbow were begun after 2 weeks, and physical therapy started 4 weeks postoperatively for active/passive range of motion of the shoulder. When muscle reinnervation was evident, motor reeducation and strengthening exercises were begun. To increase biceps contraction and assist with motor retraining, patients were first instructed to contract the FCU muscle isometrically with gripping activities and to contract the biceps muscle simultaneously in various degrees of elbow flexion. To recruit the brachialis muscle, patients were instructed to contract isometrically the muscle that the donor nerve originally innervated (pectoralis major, latissimus dorsi, triceps, or intercostal muscles) in various degrees of elbow flexion to increase brachialis muscle contraction and to assist with motor retraining. As the strength of elbow flexion increased, progressive, weight-resisted exercises were begun. Long-term follow-up EMG studies were performed in one patient to verify reinnervation of both the biceps and brachialis muscles.

Results
Evidence of reinnervation of the biceps or brachialis muscles was clinically noted at a mean of 5.3 ± 2 months postoperatively (± SD, range 1–8 months) and the mean length of follow up was 29.3 ± 15 months (± SD, range 13–53 months). At the final follow-up evaluation, elbow flexion strength was an MRC Grade 4 in five patients and Grade 4+ in three patients (Fig. 4). Follow-up EMG studies were performed in one patient (Case 2) 4 years after the reconstructive procedure. Those findings demonstrated reinnervation of the brachialis muscle that was comparable to the biceps muscle. No fibrillations or fasciculations were noted, and both muscles demonstrated motor unit potentials that were mature and polyphasic.

Fig. 2. Schematic illustration of transfers consisting of an FCU fascicle of the ulnar nerve to the biceps branch of the musculocutaneous nerve, and the medial pectoral nerve to the brachialis branch with nerve grafts. The boxed area shows orientation for Fig. 3.

Fig. 3. Intraoperative photograph showing completed nerve transfers; the FCU fascicle of the ulnar nerve is sutured directly to the biceps branch of the musculocutaneous nerve (asterisk), and a graft is used to transfer the medial pectoral nerve to the brachialis branch (arrow indicates the distal graft and repair).
No weakness in ulnar nerve function or diminished sensation was reported by any of the patients. On long-term follow-up review, the mean postoperative grip strength (50 ± 12.7 lbs, ± SD) was significantly higher than it was preoperatively (28 ± 16.4 lbs, ± SD; p < 0.05). Pinch strength was also greater postoperatively (18.2 ± 10 lbs, ± SD) compared with preoperative measurements (12.8 ± 8 lbs, ± SD) but statistical significance was not reached. Two-point discrimination in the small finger was the same or better postoperatively.

Subjectively, all patients reported satisfaction with their recovery of elbow flexion. Two of the patients have returned to their previous employment: one is a mail carrier and one is a construction worker. One patient previously worked as an electrician and mechanic in a factory and is undergoing vocational rehabilitation in preparation for different work. Of the remaining patients, who have been unable to return to work, their previous employment included parcel delivery, casino cashing, and driving a cement mixer. One patient was a competitive motorcycle racer and sustained his injury in a motorcycle accident. He has not returned to work but has resumed motorcycle riding.

During the primary brachial plexus surgery, additional nerve transfers for reconstruction of shoulder function were performed in seven of eight patients, and included transfers to the suprascapular and/or axillary nerves. Secondary procedures were performed in three patients, two of whom underwent additional surgery to restore sensation in the thumb and index finger (these procedures were performed 7 and 16 months after the initial brachial plexus reconstruction).
Nerve transfers for elbow flexion

The other patient also required tendon transfers 18 months after his injury to treat a persistent radial nerve palsy.

Discussion

The technique of nerve transfer is useful in the surgical management of large gaps or proximal nerve injuries such as those involving the brachial plexus. In proximal nerve injuries, regeneration may not occur fast enough to reinnervate the muscle before there is irreversible degeneration and fibrosis of the neuromuscular junction. Nerve transfers performed at the level of the target muscle allow faster reinnervation because of the shorter distance for regeneration to the denervated muscle; in most cases a direct end-to-end nerve repair can be used. Selection of the appropriate donor nerve will optimize the likelihood of good functional recovery; it should be close to the target muscle and it should be an expendable motor nerve to minimize donor morbidity. In selecting the donor nerve, the surgeon should consider candidates that are pure motor nerves with many motor axons and that are similar in size to the target nerve. Recruitment of the reinnervated muscle will be facilitated by the use of a nerve that connects to a synergistic muscle.

The Oberlin ulnar nerve fascicle transfer method has been shown to be a viable option for the reconstruction of elbow flexion with no functional donor morbidity. The advantages of this procedure for restoring elbow flexion include a distal dissection away from the zone of proximal injury in uninjured tissue planes, and the proximity of the nerve source to the target motor endplate, which allows faster reinnervation. The number of motor axons that can be transferred from the ulnar nerve is limited, however, because of the risk of downgrading ulnar nerve function. In Oberlin’s original description, he concluded that the ulnar nerve presents a mixed pattern of motor and sensory fibers at the arm level. Because of the mixed nature of these fascicles, a decreased number of motor axons may be directable to the musculocutaneous nerve, and this may account for the need for additional procedures such as the Steinadl flexorplasty in some patients.

The brachialis muscle is the primary one for elbow flexion, whereas the biceps muscle is primarily a forearm supinator and secondarily an elbow flexor. Therefore, reinnervation of only the biceps muscle may not provide adequate elbow flexion strength; reinnervation of the brachialis muscle as well should provide significantly more flexion strength in the elbow. Good muscle recovery depends on a critical number of motor axons reaching and reinnervating the target muscle. Maximizing the number of donor motor axons that are transferred to this target will increase the probability of achieving good muscle strength. When using Oberlin’s FCU fascicle transfer procedure the biceps branch of the musculocutaneous nerve, only a finite number of axons can be transferred from the ulnar nerve, and therefore an additional transfer to reinnervate the brachialis muscle will maximize elbow flexion strength. The donor nerves used for brachial plexus reconstruction may have been initially involved in the injury and may have recovered sufficiently for transfer. The use of the brachialis muscle to augment elbow flexion strength may be more significant in cases in which the ulnar nerve was involved in the initial injury. In four of the eight patients in our series, the ulnar nerve recovered sufficiently to provide a satisfactory donor fascicle (MRC Grade 4). The strongest recovery of elbow flexion (MRC Grade 4+) was seen in three patients and in two of these three the donor nerves for both the biceps and the brachialis were spared from the initial injury. In six cases, either the ulnar or the medial pectoral nerve showed some clinical or EMG-confirmed evidence of injury.

Our experience with augmenting the Oberlin procedure by also reinnervating the brachialis muscle demonstrated excellent recovery of elbow flexion strength. Our preference for the Oberlin FCU transfer is based on the proximity of the fascicle to the musculocutaneous nerve, which allows a direct repair very close to the motor endplate. In most of our cases, the medial pectoral nerve was used as the donor motor nerve to brachialis muscle, and a graft was required to reach the more distal brachialis branch of the musculocutaneous nerve. Other donor nerves, however, such as the intercostal, the thoracodorsal, and a triceps branch of the radial nerve, were also used to reinnervate the brachialis muscle, depending on availability. Both the thoracodorsal and the triceps branch of the radial nerve allowed a direct transfer without the need for a graft. The triceps branch is less optimal, however, than the thoracodorsal nerve, because the former innervates a muscle antagonistic to elbow flexion and can make motor retraining more difficult. The use of the thoracodorsal nerve will, however, preclude using the latissimus dorsi muscle for other secondary shoulder procedures. Both the thoracodorsal and the intercostal nerves require a separate chest incision and more dissection to harvest the donor material. Harvesting the intercostal nerves can be more tedious technically because of their small diameter. Even if a healthy proximal C-5 or C-6 nerve root or upper trunk stump is available, our procedure of choice for restoring elbow flexion is to reinnervate the brachialis branch by using the various options described earlier in conjunction with the FCU-to-biceps transfer. The proximal sources of healthy nerve stumps are thus reserved for reconstruction of the suprascapular and axillary nerves, in which the distance to cross is less.

Neurolysis of the brachialis branch of the musculocutaneous nerve from the LABC nerve component should theoretically allow more donor motor axons to be directed for reinnervation of the brachialis muscle. In our series of patients, however, this increased dissection did not produce a more favorable result. Therefore, further neurolysis to exclude the sensory component of the musculocutaneous nerve does not appear to be necessary, and sufficient motor axons appear to reach the brachialis through this nerve.

Similar to the series reported by Oberlin et al., none of our patients reported decreased ulnar nerve function after the FCU fascicle transfer, either subjectively or by quantitative sensory measures or motor strength assessments. The redundancy of the FCU innervation has been shown to be consistently sufficient to allow transfer of a fascicle without functional donor nerve morbidity. Intuitively, however, it seems appropriate to exclude the LABC nerve’s sensory component when feasible to avoid wasting valuable motor fibers in the cutaneous territory.

Surgeons who recognize that transfers in which the pectoralis major, latissimus dorsi, and triceps muscles are used will reliably restore elbow flexion can now be equally confident that similar nerve transfers will restore the same functional recovery if performed within the window for muscle

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recovery (≤ 1 year). In addition, the nerve transfer will require less dissection of the target muscle, minimizing the formation of adhesions that will limit muscle excursion, and it will take advantage of maintaining the original biceps/brachialis muscle tension with its natural origin and insertion.9

Conclusions

The Oberlin FCU fascicle transfer procedure provides a reliable source of donor motor axons for transfer in brachial plexus injuries and allows reinnervation of the biceps muscle in a timely fashion without functional donor sequelae. In some patients, however, the quantity of functioning motor axons may not be sufficient for the satisfactory recovery of elbow flexion. In those cases, the additional nerve transfer to reinnervate the brachialis muscle provides maximal recovery of elbow flexion strength.

References


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