Modified C-7 neurotization in the treatment of brachial plexus avulsion injury

Clinical article

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Object. Contralateral C-7 transfer is often used in patients with brachial plexus avulsion injury. Traditionally, the contralateral C-7 root has only been transferred to a single nerve, such as the median or radial nerve. In this study, the authors aimed to evaluate the efficacy of contralateral C-7 transfer to 2 different recipient nerves in patients with brachial plexus avulsion injuries.

Methods. Between 2004 and 2008, 10 patients with brachial plexus root avulsions underwent nerve reconstruction using a modified C-7 neurotization technique. In this procedure, the contralateral C-7 root was transferred via vascularized ulnar nerve grafts to both the musculocutaneous nerve and the median nerve on the affected side.

Results. The strength of the biceps muscles increased to M3 or M4 in 6 patients and to M2 in 2 patients. The median nerve transfers led to regained motor function and strength of the wrist and finger flexors with improvement to M3 in 5 patients. Seven patients showed notable gains of sensory function (≥ S3).

Conclusions. Contralateral C-7 transfer to 2 different recipient nerves is a feasible and efficient approach in patients with brachial plexus avulsion injuries when the donor nerve is limited. (DOI: 10.3171/2011.6.JNS101604)

Key Words • contralateral C-7 transfer • brachial plexus injury nerve transfer • root avulsion • peripheral nerve

Abbreviations used in this paper: MRC = Medical Research Council; SSEP = somatosensory evoked potential.

This article contains some figures that are displayed in color online but in black and white in the print edition.
lations concerning the ethical use of human volunteers were followed during the course of this research.

Surgical Treatment

The operation was performed under general anesthesia with the patient in the supine position. The upper extremities, shoulders, neck, and chest were prepared. We made supraclavicular transverse incisions to explore the brachial plexus on the injured side. The diagnosis of nerve root avulsion was confirmed by the findings of an avulsed dorsal root ganglion or avulsion in situ, identified by the presence of an atrophic yellowish root, with no detectable SSEPs from the scalp and no motor response from the distal muscles after root stimulation.\(^6\) Avulsions of the C-5 to T-1 roots were observed in all patients.

The surgical techniques for the exposure, confirmation, and division of the C-7 root on the uninjured side have been described in a previous study.\(^6\) Vascularized nerve grafting was performed using the ipsilateral ulnar nerve based on the superior ulnar collateral vessels as both the musculocutaneous nerve and the medial part of the median nerve were repaired (Fig. 1). A 2-stage method was adopted to connect the contralateral C-7 nerve root to the affected brachial plexus. In the first stage, the ipsilateral ulnar nerve and its dorsal cutaneous branch were severed at the level of the wrist and dissected proximally to the level of the superior ulnar collateral artery. The freed ulnar nerve distal to that level was then transferred via a pectoral subcutaneous tunnel to the contralateral side and coapted to the contralateral C-7 nerve root (Fig. 1 upper). To maintain a good blood supply for the ulnar nerve graft,\(^6\) we kept the proximal ulnar nerve intact during the first stage of the operation. After the first operation, the patient was followed up every 3 months and measurements included the Tinel sign and SSEPs evaluated along the ulnar nerve graft to detect the extent of nerve regeneration.

On approaching the axilla at the injured site, the second-stage transfer was carried out. The ulnar nerve on the affected side proximal to the pedicle of the superior ulnar collateral artery was dissected and divided proximally; it was then turned around to be coapted to the musculocutaneous nerve and the medial portion of the median nerve (Fig. 1 lower). The interval between the 2 stages ranged from 6 to 9 months (mean 8 months). As the size of the ulnar nerve graft was not sufficient to cover the cut surface of both nerves, we chose to repair the musculocutaneous nerve and the median nerve elements that were primarily responsible for the motor function of the hand (that is, the medial part of the median nerve, which originates mainly from the medial cord). For nerve repair, the internal epineurium was sutured with 10-0 nylon without the use of fibrin glue. Contralateral C-7 transfer was performed simultaneously with other nerve transfers such as accessory-to-suprascapular nerve transfer or at 4 weeks after C-7 transfers.

Postoperative Management

In all cases, a prefabricated neck splint was placed immediately after the operation. The neck splint was kept in place for 3 weeks. Physiotherapy began 4 weeks after surgery to maintain the potential range of motion in all joints. However, passive shoulder abduction beyond 90\(^\circ\) was avoided after the nerve repair. Each patient was seen weekly for 2 weeks immediately after surgery, 1 month afterward, and then every 3 months thereafter. Electromyographic evaluations and physical examinations were performed at each clinic visit to assess the degree of progress. The patients underwent electrical muscle stimulation (JNR; Shanghai XingYu Electronic Instrument Co. Ltd.) twice daily for 20 minutes at home; the stimulation sessions began 4 weeks after surgery and were stopped either when patients obtained M3 motor recovery or at 3 years after surgery if there was no sign of motor recovery. The electrophysiological studies of the donor limb were done on the unaffected upper extremity. The electrophysiological studies included motor nerve conduction velocity of the radial nerve, sensory nerve conduction velocity, and SSEPs of the median nerve.

Sensory recovery after surgery was evaluated using the British Medical Research Council grading system (range S0–S4),\(^7\) and motor recovery was assessed using a modified MRC system (Table 1). The musculocutaneous nerve was assessed by testing the strength of the biceps, and the median nerve was assessed by testing the strength of the wrist and finger flexors.

Results

The results of the electrophysiological studies of the donor limb were generally normal, except that the amplitude of SSEPs of the median nerve was slightly reduced. After the last stage of the surgery, the patients were observed for 28–50 months (mean 39.4 months). Electrophysiological examination revealed “nascent” motor unit potentials in the biceps approximately 3 months after the last stage of the operation, and “nascent” motor unit potentials in the wrist flexors and finger flexors approximately 9 months after the last stage of the operation in most patients. This indicated the successful regeneration of the contralateral C-7 nerve into the biceps, wrist flexors, and finger flexors. For most patients, weak biceps contractions could be seen approximately 4–6 months after the last stage of surgery. Weak wrist flexor and finger flexor contractions could be seen by 10–12 months after the final stage of surgery. The duration between the initial (first stage) surgery and the return of function of biceps was approximately 12–15 months. The duration between the initial surgery and the return of function of wrist flexor and finger flexor was approximately 18–21 months.

The surgical results showed noteworthy gains of sensory function (≥ S3) in the thumb, forefinger, and middle finger tips in 7 patients; the motor gains varied among patients. Among the 10 patients, the strength of the biceps muscle improved to the level of M3 in 4 patients and to M4 in 2 patients, and the strength of the muscle improved to M2 in 2 patients. The other 2 patients did not show any improvement in terms of musculocutaneous nerve motor function. In 5 patients, the median nerve regained motor function and the strength of the wrist and finger flexors.
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improved to M3 (Fig. 2), and in 2 patients, the wrist and finger flexor function improved to M2. The other 3 patients did not show any improvement in their median motor function (Table 2).

Two of the 10 patients had no sensory disturbance of the healthy limb postoperatively. The other 8 patients had numbness and pain in the fingers of the healthy limb after surgery, but these symptoms disappeared within 1 week (in 3 patients), 2 weeks (in 2 patients), 3 weeks (in 1 patient), and up to 3 months (in 2 patients). Three patients had attenuation of grip strength. Among them, 2 recovered to normal within 2 weeks, and the remaining patient recovered full function within 4 weeks. One patient had M4 weakness in the triceps that recovered completely in 2 months. One patient had M4 isolated weakness of the extensor digitorum communis that recovered completely within 1 month. Except for these findings, no other obvious adverse effects on the side of the donor limb were reported.

Discussion

Total root avulsion brachial plexus injuries have been a great challenge to peripheral nerve surgeons because they cannot be repaired and have no possibility of spon-

TABLE 1: Modified MRC grading system for muscle strength*

<table>
<thead>
<tr>
<th>Observation</th>
<th>Muscle Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>no contraction</td>
<td>0</td>
</tr>
<tr>
<td>flick or trace of contraction</td>
<td>1</td>
</tr>
<tr>
<td>active movement w/ gravity eliminated</td>
<td>2</td>
</tr>
<tr>
<td>active movement partially against gravity (≥ one-half range)</td>
<td>2+</td>
</tr>
<tr>
<td>active movement against gravity</td>
<td>3</td>
</tr>
<tr>
<td>active movement against gravity &amp; resistance</td>
<td>4</td>
</tr>
<tr>
<td>normal strength</td>
<td>5</td>
</tr>
</tbody>
</table>


Fig. 2. Photograph of a patient with total root avulsions of the right brachial plexus, showing good recovery (M3) of the biceps and the wrist and finger flexors after transfer of the contralateral C-7 to the musculocutaneous nerve and the medial part of the median nerve.
taneous recovery. At present, the most successful method to restore the affected limb function is nerve transfer.\textsuperscript{1,2,5} The possible donors include the intercostal,\textsuperscript{4,8} spinal accessory,\textsuperscript{5} phrenic,\textsuperscript{13} cervical plexus,\textsuperscript{12} and contralateral C-7 nerves.\textsuperscript{4} Contralateral C-7 nerve root transfer was first reported by Gu et al.\textsuperscript{7} in 1992. This procedure has been widely adopted in adult patients, because it provides an outflow of between 16,000 and 40,000 myelinated nerve fibers without permanent damage to the upper-limb function of the healthy donor side.\textsuperscript{17} In adults, the contralateral C-7 root was traditionally transferred only to a single nerve, such as either the median or the radial nerves.\textsuperscript{6,7} The report by Bonnel\textsuperscript{3} showed that the average numbers of nerve fibers within the C-7 root, median nerve, ulnar nerve, and radial nerve were 23,781, 15,915, 14,161, and 15,964, respectively; this demonstrated that the average number of fibers in the C-7 nerve was significantly greater than the number in the median nerve. Oberlin et al.\textsuperscript{11} reported that, for patients with C5–6 root avulsions, only 10% of the bulk of the normal functioning ulnar nerve is required to recover the functions of the musculocutaneous nerve. Therefore, the C-7 nerve contains sufficient nerve fibers to allow the recovery of both the functions of the median nerve and musculocutaneous nerve.

Recently, an experimental study confirmed that contralateral C-7 root transfer to multiple recipient nerves is a feasible and effective approach.\textsuperscript{18} In the experimental group in that study, the contralateral C-7 root was transferred to both the medial head of the median nerve and to the musculocutaneous nerve via the ulnar nerve graft, which was split and sutured to the recipient nerves; in the 2 control groups, the contralateral C-7 root was transferred to the medial head of the median nerve or to the musculocutaneous nerve alone via the traditional ulnar nerve graft. Long-term follow-up showed that the functional recovery of the median and musculocutaneous nerves in the experimental group was similar to that of the single recipient nerve in both control groups. These results provide an experimental basis for the application of C-7 root transfer to multiple recipient nerves, and on that basis, we attempted contralateral C-7 root transfers to the medial branch of the median nerve and the musculocutaneous nerve to restore elbow flexion and hand function in patients with total root avulsions.

In the study by Gu et al.,\textsuperscript{7} when the C-7 root was transferred to the musculocutaneous nerve, 67.8% of cases gained a recovery in the biceps of up to M3; when the C-7 root was transferred to the median nerve, 62.5% of cases achieved a motor recovery of the wrist and finger flexors of up to M3, and 75% of cases recovered sensory perception up to S3. In our study, the strength of the biceps muscles after surgery increased up to M3 in 6 patients (60%). The median nerve transfers led to regained motor function and strength of the wrist and finger flexors, with improvements of up to M3 in 5 patients (50%); 7 patients (70%) also achieved noteworthy sensory recovery. Although these results were not better than the transfer of C-7 to a single recipient nerve, the combined procedure can recover more function of the injured limb with a single donor nerve root. As far as cases with total nerve root avulsion of the brachial plexus are concerned, a motor recovery of 50%–60% and a sensory recovery of 70% are very useful to patients. A flail upper limb without any function is a burden for patients. They need to use their remaining healthy limb to help stabilize the flail limb. When the muscle strength of the upper limb recovers to M3 after the operation, patients regain some control over the injured limb. This frees up the normal limb and is useful for the patients to work with the normal limb. Therefore, this procedure is effective and can be used when donor nerves are limited.

In this series, a weak biceps contraction could be seen in most patients approximately 4–6 months after the final surgical procedure, while weak contractions of the wrist flexors and finger flexors could be seen by 10–12 months after the final surgery. In adults, the distance from the axilla to the point where the musculocutaneous nerve enter into the biceps muscle is approximately 10 cm, and the distance from the axilla to the point where the median nerve enters into the wrist and finger flexors is about 30 cm. Considering that nerve regenerates at a rate of 1 mm/day, it would take between 100 and 300 days, respectively, to cover these distances. With the addition of the time required to cross the nerve coaptation site(s), the time needed for a functional recovery in our series was in accordance with the known speed of axonal regeneration.

As the ulnar nerve graft does not have sufficient size to cover the cut surface of 2 nerves, the musculocutaneous nerve, along with the median nerve elements that mostly innervate the motor function of the hand (the medial part of the median nerve, which mainly originates from the median cord), were chosen for the repair to ensure a more optimal gain in motor function in the upper limb.

Contralateral C-7 transfer has been proven to be a safe procedure, with only temporary slight damage to the sensory function of the median nerve and occasional cases of postoperative pain in the donor limb.\textsuperscript{14} In this current series, 2 of the 10 patients had no sensory disturbance of the healthy limb. The other 8 patients had numbness and pain in the fingers after operation, but these symptoms disappeared within 1 week in 3 patients, 2 weeks in 2 patients, and 3 weeks in 1 patient. The symptoms took 3
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months to disappear in the remaining 2 patients. These results were similar to those of previous reports.6,7,14

Conclusions

The contralateral transfer of the C-7 root to 2 different recipient nerves is a feasible and efficient approach in patients with total avulsion of the nerve roots of the brachial plexus when the donor nerve is limited.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Hou. Acquisition of data: Lv. Analysis and interpretation of data: Lin. Drafting the article: Lin. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Hou.

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