Transfer of the phrenic nerve to the posterior division of the lower trunk to recover thumb and finger extension in brachial plexus palsy

Clinical article

HAODONG LIN, M.D., PH.D., CHUNLIN HOU, M.D., AIMIN CHEN, M.D., PH.D., AND ZHEN Xu, M.D.

Department of Orthopedic Surgery, Changzheng Hospital, The Second Military Medical University, Shanghai, China

Object. Hand function is severely impaired in cases of lower root avulsion. In the present study, the authors investigated the clinical effectiveness and safety of phrenic nerve transfer to the posterior division of the lower trunk of the brachial plexus to recover thumb and finger extension.

Methods. Between 2004 and 2006, 10 patients with brachial plexus palsy underwent phrenic nerve transfer as part of a strategy for surgical reconstruction of their plexuses. The mean patient age of was 27.2 years (range 18–44 years), and the mean interval from injury to surgery was 5.7 months (range 3–9 months). The phrenic nerve was always transferred to the posterior division of the lower trunk.

Results. The follow-up of the patients ranged from 2.5 to 4.4 years, with an average follow-up length of 3.5 years. There were no major complications related to the surgery. Eight patients recovered to Grade 3 or better (Medical Research Council grade) in extensor digitorum strength, and 7 patients recovered to Grade 3 or better in extensor pollicis strength. None of the patients had any clinical signs or symptoms of respiratory insufficiency.

Conclusions. Satisfactory thumb and finger extension can be achieved by phrenic nerve transfer to the posterior division of the lower trunk of the brachial plexus. This procedure is simple and less traumatic than that of transferring the phrenic nerve to the radial nerve. It is indicated in cases in which the brachial plexus is relatively intact at the division level. (DOI: 10.3171/2010.7.JNS091748)

Key Words • phrenic nerve • brachial plexus • nerve transfer • nerve injury

The treatment of brachial plexus avulsion poses many challenges to neurosurgeons and currently is most often treated by nerve transfer. Although various surgical procedures have been introduced for the treatment of preganglionic injuries of the C-5 and C-6 nerve root or the upper trunk, few studies have described hand reconstruction for lower brachial plexus palsies. In these cases, because few tendon transfer options are available in the forearm, traditional tendon transfer is difficult to perform. Attachment of extensor tendons to the distal side of the dorsal radius (that is, tenodesis) has been unsuccessfully used for finger extension. Neurological restoration of thumb and finger extension therefore is a feasible alternative for improved results.

Since the phrenic nerve is the largest branch of the cervical plexus, its transfer has been widely used for treating brachial plexus avulsion injury. Terzis et al. have transferred the phrenic nerve to the radial nerve to recover thumb and finger extension; however, this procedure has 2 disadvantages. First, due to the short length of the nerve accessible through a conventional supraclavicular exposure, the nerve must be lengthened using a nerve graft. Second, since the diameters of the phrenic and radial nerves are quite different, it is difficult to anastomose the two. Wang et al. reported that the nerve fibers innervating the extensor digitorum and extensor pollicis muscles mostly originate from the posterior division of the lower trunk. We hypothesized that the phrenic nerve...
Phrenic nerve transfer could be transferred to the posterior division of the lower trunk to recover thumb and finger extension successfully. The purpose of this study was to evaluate the clinical effectiveness and safety of phrenic nerve transfer in the restoration of thumb and finger extension.

**Methods**

Between October 2004 and December 2006, 10 patients (9 men and 1 woman) who presented with brachial plexus injury were included in this study (Table 1). The left side was affected in 7 cases and the right side in 3 cases. Patients ranged in age from 18 to 44 years (mean 27.2 years). The main mechanism of injury was a motorcycle accident. The interval between injury and operation ranged from 3 to 9 months (mean 5.7 months). The injury involved total root avulsion in 4 patients and lower plexus root avulsion in 6. Brachial plexus avulsion injury was diagnosed during clinical evaluation and by using electromyography. The normal function of the phrenic nerve bilaterally and normal pulmonary function were confirmed by chest radiography and pulmonary function testing. Ethics approval was granted by our institution, and informed consent was obtained from all patients.

**Surgical Procedure**

After induction of general anesthesia, the patient was placed supine, and a pillow was placed under the shoulders with the head turned to the uninjured side. The brachial plexus was exposed through an incision from the neck to the inner aspect of the upper limb, as described by Gu et al.13 The phrenic nerve was identified on the anterior surface of the anterior scalene muscle. Intraoperative somatosensory evoked potential monitoring was performed to confirm root avulsion, and a nerve stimulator was used to confirm the integrity of the phrenic nerve. The phrenic nerve was dissected as far distally as possible, transected at the upper margin of the clavicle just before its entry into the thoracic cavity, and mobilized laterally for transfer. The lower trunk of the brachial plexus was pulled upward so that the posterior division of the lower trunk could be explored. The posterior division of the lower trunk was dissected at the trunk-division level, and under microscope guidance the proximal end of the phrenic nerve was transfened to the posterior division of the lower trunk directly and was attached using 9-0 nylon sutures (Figs. 1 and 2). If the phrenic nerve could not be directly coapted to the posterior division of the lower trunk, the 2 nerves were bridged by a nerve graft. Other nerve transfers such as contralateral C-7 root transfer to the median nerve and accessory-to-suprascapular nerve transfer were performed simultaneously when appropriate.

**Postoperative Treatment**

After the procedure, a head, thorax, and shoulder spica was applied for 4–6 weeks to avoid tension at the site of neurotization. Patients received routine postoperative care and in most cases were discharged from the hospital approximately 1 week after surgery. During follow-up, electromyography and physical examination were performed approximately every 3 months.

**Results**

Patient follow-up ranged from 2.5 to 4.4 years (mean 3.5 years), and there were no major complications related to the procedure. The mean primary hospital stay was 6 days (range 4–8 days). In all cases, the phrenic nerve reached the thoracic cavity, and mobilized laterally for transfer. The lower trunk of the brachial plexus was pulled upward so that the posterior division of the lower trunk could be explored. The posterior division of the lower trunk was dissected at the trunk-division level, and under microscope guidance the proximal end of the phrenic nerve was transferred to the posterior division of the lower trunk directly and was attached using 9-0 nylon sutures (Figs. 1 and 2). If the phrenic nerve could not be directly coapted to the posterior division of the lower trunk, the 2 nerves were bridged by a nerve graft. Other nerve transfers such as contralateral C-7 root transfer to the median nerve and accessory-to-suprascapular nerve transfer were performed simultaneously when appropriate.

**TABLE 1: Transfer of the phrenic nerve to the posterior division of the lower trunk of the brachial plexus in 10 patients***

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Lesion Side, Type</th>
<th>Interval (mos)†</th>
<th>FU (yrs)</th>
<th>MRC</th>
<th>ED</th>
<th>EP</th>
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<tbody>
<tr>
<td>1</td>
<td>23, M</td>
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<td>7</td>
<td>4.4</td>
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<td>44, M</td>
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<td>3.9</td>
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<td>18, M</td>
<td>rt, lower plexus avulsion</td>
<td>6</td>
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<td>3</td>
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<td>34, M</td>
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<td>3.3</td>
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<td>rt, total avulsion</td>
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<td>4</td>
<td>3.8</td>
<td>4.3</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

* ED = extensor digitorum; EP = extensor pollicis; FU = follow-up.
† Between injury and surgery.
the posterior division of the lower trunk. All patients underwent sufficient follow-up, and none showed any clinical signs or symptoms of respiratory insufficiency.

Electrophysiological examination revealed newly acquired potentials in the extensor digitorum and extensor pollicis muscles in most patients. These appeared approximately 18–24 months after the operation, indicating the successful regeneration of the phrenic nerve into the extensor digitorum and extensor pollicis muscles. Functional evaluation showed that 8 patients (80%) recovered to Grade 3 or better (according to the British MRC system) in extensor digitorum muscle strength, and in the other 2 cases (20%) the extensor digitorum muscles strength reached MRC Grade 1 or 2. Similarly, 7 patients (70%) recovered to Grade 3 or better in extensor pollicis strength, and in the other 3 cases (30%) the extensor pollicis strength reached MRC Grade 1 or 2.

**Discussion**

Nerve transfer is a valid surgical procedure for functional restoration after nerve lesions. To date, various nerve transfer procedures have been initiated. Since 1970, Gu and his colleagues have used phrenic nerve transfer. They published the results of their the first clinical series in 1989, in which they reported good motor recovery in 164 patients who had undergone this procedure. Since then, the phrenic nerve has been transferred to various recipient nerves, including the musculocutaneous, thoracodorsal, suprascapular, axillary, radial, and median nerves. The rate of effectiveness of this procedure has been reported to be as high as 80%, and significant disturbance of pulmonary function has rarely been reported. The high rate of effectiveness can be attributed to the numerous motor axons found in the phrenic nerve. Because of the special character of the phrenic nerve, it has been thought that the indications for phrenic nerve neurotization can be expanded by performing new procedures.

Although various surgical procedures have been introduced for the treatment of preganglionic injuries of the C-5 and C-6 nerve root or the upper trunk, very few published reports have dealt with hand reconstruction for lower-type palsies of the brachial plexus, and the results that have been published have tended to indicate a poor outcome. Options for restoration of thumb/finger extension depend on the extent of injury and availability of donor motors, be it muscle-tendon unit or motor nerve branch. When no motor unit is available or spareable, static orthopedic procedures such as tenodesis or arthrodesis are applied. Fixing the extensor tendons of the thumb and fingers to the distal radius triggers thumb and finger extension when the wrist is flexed by way of the tenodesis effect. When there are motor branches available for transfer and the interval between injury and surgical intervention is not too long, neurotization procedures can be used. Transfer of the brachialis motor branch to the posterior interosseous nerve via a nerve graft has been attempted recently, and successful finger extension was achieved. Thumb extension, however, was not restored.

The brachial plexus is simply visualized as beginning with the ventral rami of spinal nerves C-5, C-6, C-7, C-8, and T-1 in the neck and terminating as branches of the musculocutaneous, median, ulnar, radial, and axillary nerves in the axilla. The intermediate portion is displayed as 3 trunks, divisions, and cords. The extensor digitorum and extensor pollicis muscles are innervated by the radial nerve. If the phrenic nerve is transferred to the radial nerve to recover thumb and finger extension, the short length of nerve available through the conventional supraclavicular exposure would necessitate lengthening by interposition of a nerve graft. Furthermore, the diameters of the phrenic and radial nerves are quite different. As we know, the radial nerve receives fibers from the posterior cord, the latter of which is formed by the union of the posterior divisions of the upper, middle, and lower trunks. Wang et al. suggested that the extensor digitorum and extensor pollicis muscles are mainly innervated by the posterior division of the lower trunk of the brachial plexus. In their electrophysiological study, they confirmed that the nerve fibers innervating the extensor digitorum and extensor pollicis muscles originate mainly from the posterior division of the lower trunk.
Phrenic nerve transfer

the lower trunk. On the basis of their electrophysiological study and our anatomical study of the topography of the motor branch of the extensor digitorum and extensor pollicis in the brachial plexus, we advocate phrenic nerve transfer to the posterior division of the lower trunk to restore thumb/finger extension. Using this approach, we obtained an overall effective recovery rate of 80% for the extensor digitorum and 70% for the extensor pollicis. This procedure does not require a long nerve graft, and it provides effective and reliable results for thumb/finger extension. The diameter of these 2 nerves is similar, and it is easy to coapt them. In the present study, no respiratory problems were found in any of the patients. Therefore, it is recommended as a possible option for the restoration of thumb/finger extension in brachial plexus injuries in which the structures at the division level of the brachial plexus are relatively intact. This procedure is, however, unsuitable in cases in which the structures at the division level of the brachial plexus are extensively damaged. Other nerve transfers such as contralateral C7-to-median nerve to restore grasp in the hand could be performed simultaneously when appropriate.

In our transfer, the course of axonal regeneration for reinnervation is about 40–50 cm. Considering that the speed of axonal regeneration is 1 mm per day, it takes about 400–500 days for the extensor digitorum to be reinnervated. Electrophysiological examination revealed that nascent action potentials in the extensor digitorum and extensor pollicis appeared approximately 18–24 months after the operation. This is in accord with the estimated time needed for regeneration and reinnervation.

Since the posterior division of the lower trunk is located beneath the clavicle, it may be difficult for an inexperienced surgeon to explore the posterior division of the lower trunk through a supraclavicular incision. The entire brachial plexus of the injured side can be exposed through a combined incision superior and inferior to the clavicle, and the clavicle can be osteotomized. It is then easier to explore the posterior division of the lower trunk. In the present series, we successfully explored the entire posterior division of the lower trunk using a supraclavicular incision. Based on our experience, the lower trunk should be explored first. This portion of the brachial plexus should be pulled upward, and then the posterior division of the lower trunk can be easily explored. The phrenic nerve should be dissected as far distally as possible, and the posterior division of the lower trunk should be severed as proximal as possible. If the phrenic nerve cannot be directly coapted to the posterior division of the lower trunk, the 2 nerves can be bridged by a nerve graft. Other nerve transfers can be performed simultaneously when appropriate.

We believe that targeting the thumb and finger extensor fascicles located at the posterior division of the lower trunk for neurotization in lower-type injuries of the brachial plexus is a rational choice. This procedure is more likely to succeed than targeting the finger flexors because the muscle power required for adequate release is much less than that required for hand grasping. Therefore, phrenic nerve transfer will still work even in cases of incomplete reinnervation since the amount of muscle force required for thumb and finger extension is minimal.

In our series, after transection of the phrenic nerve, unilateral diaphragmatic paralysis was observed on plain chest radiographs in all patients, but respiratory dysfunction was absent because of the compensation afforded by the intact diaphragm. The safety of phrenic nerve transfer has been reported in detail in previous literature\textsuperscript{6,12,14,20} and therefore is not addressed in this paper.

Conclusions

Satisfactory thumb and finger extension can be achieved by phrenic nerve transfer to the posterior division of the lower trunk. This procedure is simple and less traumatic than that of transferring the phrenic nerve to the radial nerve. It is indicated in cases in which the brachial plexus is relatively intact at the division level.

Disclosure

The authors report no conflict of interest concerning the materials and 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, Lin. Acquisition of data: Chen. Analysis and interpretation of data: Lin, Xu. Reviewed final version of the manuscript and approved it for submission: all authors.

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