Hand prehension recovery after brachial plexus avulsion injury by performing a full-length phrenic nerve transfer via endoscopic thoracic surgery

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Object. The functional recovery of hand prehension after complete brachial plexus avulsion injury (BPAI) remains an unsolved problem. The authors conducted a prospective study to elucidate a new method of resolving this injury.

Methods. Three patients with BPAI underwent a new procedure during which the full-length phrenic nerve was transferred to the medial root of the median nerve via endoscopic thoracic surgery support. All 3 patients were followed up for a postoperative period of >3 years.

Results. The power of the palmaris longus, flexor pollicis longus, and the flexor digitorum muscles of all 4 fingers reached Grade 3–4/5, and no symptoms of respiratory insufficiency occurred.

Conclusions. Neurotization of the phrenic nerve to the medial root of the median nerve via endoscopic thoracic surgery is a feasible means of early hand prehension recovery after complete BPAI. (DOI: 10.3171/JNS/2008/108/6/1215)

Key Words • brachial plexus injury • endoscopic thoracic surgery • hand prehension • medial root of median nerve • neurotization • phrenic nerve

THE treatment of complete BPAI is a demanding and difficult surgery in the upper extremity. Currently, nerve transfer is the main method of treating BPAI.\cite{22} However, the traditional means of nerve transfer lead to poor functional recovery of hand prehension, mainly attributable to the long distance between the nerve anastomosis site and the reinnervated antebrachial muscle.

Phrenic nerve transfer, which was initiated by Gu,\cite{13} has been widely used in many centers because of its efficacy and lack of significant harm to a patient’s pulmonary function.\cite{5,31,36,42} The traditional surgical method involves severing the PN before it enters the thoracic cavity and transferring it to the acceptor nerve. Full-length PN harvesting assisted with endoscopic thoracic surgery was introduced by Xu and colleagues\cite{21} in 2002. This technique obviously shortens the gap from the distal end of the PN to the forearm muscles. It is a promising method of restoring hand prehension. Here, we report the preliminary results in 3 patients with BPAI in whom PN transfer to the medial root of the median nerve was performed by using endoscopic thoracic surgery support at our institute between 2002 and 2003.

Clinical Materials and Methods

The study included 3 men who had undergone surgery between 2002 and 2003. They were treated within 3 months after injury (Table 1).

Complete BPAI was diagnosed based on clinical evaluation and electromyography, and the definitive diagnosis of root avulsions was identified at surgery, given the absence of the C-5 to T-1 nerves within the intervertebral foramen. Normal functioning of the PN bilaterally was proven by radiographs of the chest during deep inspiration and full expiration. Pulmonary function tests and electrocardiography were also routinely performed to identify any pulmonary dysfunction or cardiac disease. Study approval was granted by the institution ethics committee, and informed consent was obtained from all patients.

Given the complete BPAIs, multiple nerve transfers were performed to restore function of the shoulder, elbow, and hand, including accessory nerves to the suprascapular nerve for shoulder abduction, motor branch of the intercostal nerve to musculocutaneous nerve for elbow flexion, lateral cutaneous branch of the intercostal nerve to the lateral root of the median nerve for sensation in the hand, contralateral C-7 root to radial nerve for elbow and wrist extension, and the new choice of full-length PN to the medial root of the median nerve for hand prehension. Most of these neurotization methods have often been reported, and now we discuss mainly the situation of the full-length PN transferred to the medial root of the median nerve.\cite{25,30,38}

Surgical Procedure

Patients were placed horizontal with slight elevation of their backs during surgery. Double-lumen tube intubation was used, and general anesthesia was induced. The entire trajectory of the brachial plexus was exposed through an incision from the neck to the inner aspect of the upper limb,
as described by Gu13 and Narakas,21 to identify the nerve avulsion from the intervertebral foramen. The PN was located on the anterior surface of the scalenus anticus muscle. Intraoperative somatosensory evoked potential testing was routinely performed to confirm the root avulsion. A nerve stimulator was used to confirm the integrity of the PN. One-lung ventilation was initiated, and endoscopic thoracic surgery was begun.

Initially, a small 1–1.5-cm incision was made at the intersection of the anterior axillary line and the 5th or 6th intercostal space. Subcutaneous tissue and intercostal muscle were blunt dissected using vessel forceps, and an optical cavity was created. A 10-cm thoracoscope was then inserted to get the inner image to display. If the lung was well collapsed, the PN, accompanied by the pericardiophrenic artery and veins, could be identified clearly adjacent to the mediastinum. Thereafter, 2 additional incisions were made at the intersection of the third intercostal space with the midclavicular line and in the second intercostal space 2 cm lateral to the parasternal line. Forceps were forced into the thoracic cavity through the 2 incisions under the thoracoscope. Operating instruments could penetrate the incisions, which were sufficiently enlarged. An endoscopic clamp, scissors, and bipolar electrocoagulator hemostasis were most commonly used. The pleura-covered PN was divided by an endoscopic clamp and scissors on the lateral side of the pericardium as near the diaphragm as possible and then gently elevated from the pleura, which was incised and separated along the PN by using combined operating instruments. The nerve was freed without the pericardiophrenic vessels, as there was no significant difference in the clinical results between nonvascularized and vascularized full-length PN transfers44 and because the procedure was much simpler. The nerve was traced proximally to the subclavian vessels and nerves were pulled in an external direction, and after asserting that no vessel or nerve was nearby, forceps were forced into the thoracic cavity at the intersection of the fourth intercostal space and the median axillary line approximately, with the aid of the thoracoscope. Long forceps were then inserted, again with the help of the thoracoscope, and the PN was nipped and pulled out of the thoracic cavity and was always long enough to get to the axillary fossa. After asserting that there were no hemorrhagic spots, air was forced into the collapsed lung to make sure the lung was expanding well. In the meantime, the length of the outer PN had to be carefully protected, as the PN usually drew back 1–2 cm because it had been a bit twisted by the ventilated lung. Nevertheless, the PN was long enough to reach the axillary fossa even if the lung fully expanded. It was led to the medial root of the median nerve and anastomosed in an end-to-end manner by using 4 interrupted 10-0 sutures through the epineurium and perineurium of the 2 nerves (Fig. 1). A chest tube was routinely placed and later removed when the pleura was believed to be sealed, usually on the 3rd postoperative day with radiographic evidence of the fully expanded lung.

### Postoperative Management

After the procedure, a brace45 was applied and kept in place for 4 weeks to avoid tension on the neurotization. All patients were asked to begin a strict deep respiration exercise (daily exercises of 500–1000 finger and elbow flexions during deep breathing) 3 months after the surgery.42 Pulmonary function testing, electromyography evaluation, and physical examination were performed approximately every 3 months to check patient progress.

### Results

All 3 patients were followed up for a postoperative period > 3 years. None of the patients had any clinical signs or symptoms of respiratory insufficiency. Pulmonary function testing revealed evidence of depressed pulmonary function during 6 months after the operation, but this capacity recovered to preoperative levels or even better within 1 year after surgery in all 3 patients.

Electrophysiological examination showed that the new potential in the forearm flexor muscle (we tested it at the middle point of the forearm) appeared 9–12 months postoperation. A functional evaluation revealed that the power

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**TABLE 1**

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs)</th>
<th>Sex</th>
<th>Side of Injury</th>
<th>Cause of Injury</th>
<th>Interval From Injury to Op (mos)</th>
<th>New Muscle Potential Appeared (mos postop)</th>
<th>Recovery of M3 (mos postop)</th>
<th>Flexor Digitorum Superficialis &amp; Profundus</th>
<th>Flexor Pollicis Longus</th>
<th>Palmaris Longus</th>
<th>Flexor Carpi Radialis</th>
<th>Pronator Teres</th>
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* Muscle strength ratings were based on the Medical Research Council scale.
of the palmaris longus, flexor pollicis longus, and flexor digitorum muscles of all 4 fingers reached Grade 3/5, according to the Medical Research Council rating system, 12–18 months after surgery. After at least 3 years of follow-up, the function in 2 patients reached Grade 4/5, and in 1 patient it remained Grade 3/5 (Table 1 and Fig. 2).

Discussion

Brachial plexus injuries continue to occur despite an increasing awareness of the risk factors. The treatment of BPAI involves demanding surgery in a difficult area of the upper extremity. Available surgical procedures include nerve grafting, nerve transfer, and reconstructive procedures such as free muscle transplantation with nerve transfer.

Nerve transfers, or neurotizations, traditionally have been used for otherwise irreparable brachial plexus root avulsion injuries and have developed quickly. Nowadays, nerve transfer is one of the main methods of treating BPAI, and some commonly used neurotizations in brachial plexus reconstruction have been established. Neurotizations are successfully performed to reanimate denervated muscles for elbow flexion and shoulder abduction, but more distal function, such as hand prehension, still poses a problem. Therefore, the restoration of prehension following complete avulsion of the brachial plexus has been the focus of recent interest in reconstruction of the upper limb following brachial plexus injuries.

To restore hand functions, intercostal nerves have been sutured to the radial or median nerve; however, motor recovery was poor for either nerve transfer. Transfer of the intercostal nerves to the median nerve has failed to restore finger function. Doi and colleagues have pointed out that the distance between the site of nerve anastomosis and the neuromuscular junction of the forearm muscles was too great and that regenerated axons took > 1.5–2 years after nerve transfer to reach the muscle, which led to muscular atrophy. Furthermore, misdirection of the regenerating axons frequently occurred. Consider that the median nerve contains ~ 16,000 myelinated axons and its cutaneous fibers occupy ~ 67% of its fascicular cross-sectional area. Available donor nerves contain fewer fibers: the phrenic nerve contains ~ 1700–2700 myelinated axons (although according to Ma and associates, 2500–2800 myelinated axons); the spinal accessory nerve, 1500–2200 myelinated axons; the motor branch of a single intercostal nerve, ~ 400–1300 myelinated axons; and the motor branch of the cervical plexus, an average of 700–900 myelinated axons. Thus, some authors have doubted that any attempt to regenerate the median nerve (neurotization) by using any one of these donor nerves will be sufficient to reinnervate all of its fibers. A contralateral C-7 transfer has been introduced by Gu et al. for reconstruction in patients with complete brachial plexus lesions and has produced encouraging results; that is, there has been little if any donor site morbidity with the use of either the entire nerve or merely a portion of it. Considering that synchronous movement with the unaffected side is required, useful hand prehension has failed in a large portion of patients. Doi and associates have advised using free muscle transfer to provide reliable and powerful motor recovery of finger function, because the neuromotor units of the free muscle are in the upper arm and the nerve to the muscle is purely motor. However, there are some disadvantages, such as being more traumatic and involving the risk of flap necrosis.

In a study of the median nerve in the upper arm, internal topographical features of the fascicular groups of the median nerve were observed by Zhao et al., who presented a new method of selective neurotization of the median nerve. The full length of the PN was harvested through a thoracot-
According to many authors' experiences, on the other hand, there is a reciprocal relationship between the number of motor units in a reinnervated muscle and the motor unit force production, with the former increasing as much as 16- to 25-fold as the number of axons is reduced. This motor unit remodeling with increased innervation ratios is a compensatory mechanism whereby a reduced number of axons attempt to reinnervate all denervated muscle fibers. Needham-Shropshire and colleagues reported that only 9% control strength was clinically needed for human triceps brachii muscles weakened by spinal cord injury to shorten against gravity. Thus, it is doubtful that the nerve graft used to match the nerve fiber is necessary.

By general consensus, the medial root of the median nerve is considered as the motor root because it has more motor fibers and it innervates the palmaris longus, flexor digitorum superficialis and profundus, thenar, and lumbrical muscles. The lateral root has more sensory axons. The function of hand prehension comes almost exclusively from the medial root, and the full-length PN will surely reach the medial root of the median nerve. According to some anatomical research, the mean diameter of the PN at its superior point in a male patient is 2.31 mm (right side) and 2.50 mm (left side)—close to the diameter of the medial root of the median nerve, which is 2.53 mm (49.55%), 3.03 mm (35.35%), or 2.45 mm (15.10%). Therefore, transferring the PN to the medial root of the median nerve seems to be a feasible way to restore hand function, and the preliminary results of this study have confirmed it.

Full-length PN transfer by endoscopic thoracic surgery support was introduced in 2002 by Xu et al. Compared with thoracotomy exposure, this new technique will obviously minimize trauma to the patient and be easily accepted. Nowadays, the concept of minimally invasive surgery is more commonly accepted. Therefore, as long as the surgeon has the skills to perform the thoracoscopy technique and is familiar with the PN in the thoracic cavity, it is possible that full-length PN transfer via endoscopic thoracic surgery will replace thoracotomy.

Conclusions

Generally speaking, partial hand prehension function can be restored by full-length PN transfer to the medial root of the median nerve by using endoscopic thoracic surgery. We provide a new choice in dealing with hand prehension recovery after complete brachial plexus injury, and this new technique can expand the surgical strategies of surgeons facing a complete BPAI.

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