Brachial plexus palsies of C7–T1 result in the complete loss of hand function, including finger and thumb flexion and extension as well as intrinsic muscle function. The task of reanimating such a hand remains challenging, and so far there has been no reliable neurological reconstructive method for restoring hand function. The authors aimed to establish a reliable strategy to reanimate the paralyzed hand. Two patients had sustained C7–T1 complete lesions. In the first stage of the operative procedure, a supinator motor branch to posterior interosseous nerve transfer was performed with brachialis motor branch transfer to the median nerve to restore finger and thumb extension and flexion. In the second stage, the intact brachioradialis muscle was used for abductorplasty to restore thumb opposition. Both patients regained good finger extension and flexion. Thumb opposition was also attained, and overall hand function was satisfactory. The described strategy proved effective and reliable in restoring hand function after C7–T1 brachial plexus palsies.

Case Reports

History and Examination. Preganglionic lesions of C7–T1 were diagnosed in two patients. General data for these patients are listed in Table 1. Both patients manifested signs positive for Horner syndrome. The movement of their shoulder and elbow was normal. Wrist flexion and extension were preserved with marked radial deviation given the loss of extensor carpi ulnaris and flexor carpi ulnaris muscle function. There was no active movement of the fingers and thumb. Pinprick sensation disappeared in the C7–T1 dermatomes.

Electrophysiological testing revealed normal innervation in the muscles innervated by the C-5 and C-6 nerve roots and total denervation in the muscles innervated by the C-7, C-8, and T-1 nerve roots, suggesting preganglionic lesions of C-7, C-8, and T-1.

First Operative Stage: Nerve Transfer. In the first operation, the supinator and brachialis muscles and their motor branches were identified (Fig. 1). Electrical stimulation elicited strong contraction of the muscles. To further confirm the muscles were intact, intraoperative electromyography was used, and normal compound muscle action potentials were recorded for these two muscles. One motor branch of the supinator muscle was then divided and directly transferred to the PIN (Fig. 2A and B). In

This article contains some figures that are displayed in color online but in black-and-white in the print edition.
addition, one motor branch of the brachialis muscle was transferred to the median nerve using 9-0 nylon sutures. In Case 1, a 7.5-cm free sural nerve graft was used to bridge the gap between the brachialis motor branch and the AIN (Fig. 2C and D). In Case 2, the brachialis motor branch was connected with the posterior fascicular group of the median nerve at the same level in the upper arm (Fig. 2E and F), because a previous anatomical study has shown that the fascicles destined to the finger flexors are largely located in the posterior portion of median nerve at this level. A wrist-to-arm splint was used to protect the nerve sutures for 4 weeks before rehabilitation commenced.

**Second Operative Stage: Tendon Transfer.** After flexion and extension of the fingers recovered (≥ M3, British Medical Research Council grading⁹), both patients underwent a second operation for thumb opposition (abductorplasty). The distal insertion of the brachioradialis tendon was detached from the radius (Fig. 3A) and elongated by the palmaris longus tendon graft (Fig. 3B) before weaving it into the tendinous portion of the abductor pollicis brevis and extensor pollicis longus muscles (Riordan’s technique) to produce full thumb opposition (Figs. 3C and D and 4). The hand and forearm were then immobilized in a splint for 4 weeks before rehabilitation exercise focusing on thumb-finger opposition commenced.

**Postoperative Course.** The patients were required to return every 3–4 months after each operation for clinical and electrophysiological evaluation. Neither patient

*TABLE 1: Summary of general data and baseline preoperative function in 2 patients with C7–T1 brachial plexus palsy*

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Mechanism of Injury</th>
<th>Surgical Delay (mos)</th>
<th>FU Period (mos)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>45, M</td>
<td>motorcycle accident</td>
<td>3</td>
<td>36</td>
</tr>
<tr>
<td>2</td>
<td>18, M</td>
<td>machine traction</td>
<td>1.5</td>
<td>20</td>
</tr>
</tbody>
</table>

* The right side was affected in both patients. Neither patient had finger flexion and extension or thumb opposition. FU = follow-up.
experienced problems in elbow flexion or forearm supination after surgery. In both cases, the first sign of electrophysiological recovery—that is, nascent motor unit potential of extensor digitorum communis muscle during voluntary contraction—appeared 3 months after the first operation, and finger extension was noticed after another 3–6 months (Table 2). Finger flexion was noticed at 12 and 9 months in Cases 1 and 2, respectively. In Case 1, the muscle strength of the extensor digitorum communis, extensor carpi ulnaris, and extensor pollicis longus muscles reached M3 at 21 months after surgery. The muscle strength of the flexor pollicis longus and flexor digitorum profundus muscle of the index finger recovered to M3 at 2 years after surgery (Video 1).

Fig. 2. Intraoperative photographs and schematics showing transfer of the supinator motor branch to the PIN and the brachialis motor branch to the median nerve.  

A and B: The supinator motor branch was divided and transferred to the PIN without tension.  
C and D: Case 1. A 7.5-cm nerve graft was used to transfer the brachialis motor branch to the AIN.  
E and F: Case 2. The brachialis motor branch was directly transferred to the posterior portion of the median nerve in the upper arm without nerve graft. Copyright Cheng-Gang Zhang. Published with permission.
Restoration of hand function in C7–T1 brachial plexus palsy

**Video 1.** Case 1. Recovery of fingers and thumb extension and thumb and index finger flexion. Copyright Cheng-Gang Zhang. Published with permission. Click here to view with Media Player. Click here to view with Quicktime.

The patient in Case 2 achieved a full range of finger (index, middle, and ring) and thumb extension at 12 and 18 months, respectively, after surgery (Fig. 5), and because the brachialis motor branch was transferred to the posterior portion of the median nerve in the upper arm, the patient could flex not only his thumb and index finger but also his middle, ring, and little fingers (Video 2).

**Video 2.** Case 2. Good recovery of finger and thumb extension and flexion. Copyright Cheng-Gang Zhang. Published with permission. Click here to view with Media Player. Click here to view with Quicktime.

After the second operation, the patient in Case 1 could only oppose the thumb with the index finger given the lack of flexion in the rest of his fingers, whereas the patient in Case 2 regained thumb to index, middle, and ring finger pulp opposition (Fig. 6). Both patients could freely open their hands and grasp big objects (for example, a water bottle) or pick up small objects (for example, a pen) from the table. They both think the previously paralytic hand became functional and useful to their daily living (Videos 3 and 4).

**Video 3.** Case 2. Patient function in picking up a bottle from the table and putting it back. Copyright Cheng-Gang Zhang. Published with permission. Click here to view with Media Player. Click here to view with Quicktime.

**Video 4.** Case 2. The patient was able to pick up small objects, for example, a pen. Copyright Cheng-Gang Zhang. Published with permission. Click here to view with Media Player. Click here to view with Quicktime.

The patient in Case 2 even resumed writing with the reconstructed hand (Video 5).

**Video 5.** Case 2. The patient resumed writing. Copyright Cheng-Gang Zhang. Published with permission. Click here to view with Media Player. Click here to view with Quicktime.

**Fig. 3.** Intraoperative photographs of brachioradialis tendon transfer to the abductor pollicis brevis muscle for thumb opposition. **A:** The distal insertion of the brachioradialis tendon was detached from the radius. **B:** The palmaris longus tendon was used to lengthen the brachioradialis tendon. **C:** The elongated tendon was woven with the tendinous portion of the abductor pollicis brevis and extensor pollicis longus muscles to produce sufficient opposition. **D:** Immediate view of the hand after the tendon suture was completed. The thumb is in full pronation and opposition.

**Fig. 4.** Drawings of abductorplasty tendon transfer to aid in thumb opposition. Copyright Cheng-Gang Zhang. Published with permission.
There was only mild sensory recovery in the ulnar aspect of the forearm; however, protective sensibility in the ring and little fingers and ulnar aspect of the hand was unimproved (Fig. 7).

Discussion

Brachial plexus palsies of C7–T1 are rare, but they lead to a complete loss of hand motion, including finger and thumb flexion and extension as well as intrinsic muscle function. Hence, the task of reanimating such a hand is a great challenge.

Finger Flexion

There have been reports of successful restoration of finger flexion in C7–T1 palsy through brachialis motor branch transfer to the median nerve. As for whether direct repair or transfer to the AIN via a nerve graft is superior, the outcomes of the two featured cases seem to favor direct repair of the posterior portion of the median nerve, since that patient (Case 2) regained flexion in his thumb, index finger, and middle finger (M3) as well as his ring and little fingers (M2), and his overall functional recovery was therefore better than that in the other patient.

Finger Extension

So far, there is no reliable neurological reconstructive method for restoring finger extension in lower plexus palsy. Therefore, some authors prefer tendon transfer, free muscle transfer, or extensor tenodesis techniques, but the limited choice of available muscles in the forearm determines the limited recovery after these procedures. Extraplexal neurotizations, such as those involving the multi-intercostal nerve or the contralateral C-7 nerve, were not effective in finger extension either. Palazzi et al. has attempted to repair the PIN with the brachialis motor nerve via a 9-cm nerve graft in one case. That patient attained M3 muscle strength in metacarpophalangeal joint extension. Yet, there was only M1 muscle strength in the extensor pollicis longus muscle, probably because of the long distance between the donor nerve (brachialis motor branch in the upper arm) and its recipient nerve (PIN in the forearm). Therefore, we prefer to save the brachialis motor branch for median nerve repair in the upper arm to obviate the need for a long nerve graft. Since October 2007, supinator motor branch transfer to the PIN has been successfully used in our clinic. This method has proved reliable, effective, and prompt in restoring finger and thumb extension. It was beneficial even in a delayed case in which the operative interval between trauma and surgery exceeded 15 months, because of the short regeneration distance between the motor donor nerve and its recipient. The patients could not only extend all metacarpophalangeal joints and the interphalangeal joint of the thumb, but they also had M3 recovery of the extensor carpi ulnaris muscle. The preoperative radial deviation of the wrist was therefore corrected with recovery of the extensor carpi ulnaris muscle, which could become a tendon donor in a late-stage reconstruction. Since this distal neurotization technique offers the opportunity for recovery

<table>
<thead>
<tr>
<th>Case</th>
<th>Muscle</th>
<th>3</th>
<th>6</th>
<th>9</th>
<th>12</th>
<th>15</th>
<th>18</th>
<th>21</th>
<th>24</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>EDC</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>ECU</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>EPL</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>FPL</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>FDP (index)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>EDC</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>ECU</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>EPL</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>FPL</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>FDP</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

* ECU = extensor carpi ulnaris; EDC = extensor digitorum communis; EPL = extensor pollicis longus; FDP = flexor digitorum profundus; FPL = flexor pollicis longus; — = not applicable because no longer followed up.

Fig. 5. Case 2. Photograph showing full extension of the fingers and thumb in the metacarpophalangeal joints 18 months after transfer of the supinator motor branch to the PIN.
Restoration of hand function in C7–T1 brachial plexus palsy

of a group of extensors (extensor digitorum communis, extensor pollicis longus, extensor indicis proprius, extensor digiti minimi, and extensor carpi ulnaris muscles), its advantage is apparent, compared with Bertelli's supinator muscle transfer technique, in which the supinator muscle is transferred to the extensor pollicis brevis muscle for thumb extension only.1

Fig. 6. Case 2. Photographs showing the recovery of thumb-finger opposition after abductorplasty. A: Thumb–index finger opposition. B: Thumb–middle finger opposition. C: Thumb–ring finger opposition. Note the skin ulcer in the pulp of the ring finger after a trivial burn.

Since nerve repair is unlikely to succeed in restoring thumb opposition, we turned to tendon transfer techniques. In a patient with C7–T1 palsy, the intact functioning muscles in the forearm include the brachioradialis, extensor carpi radialis longus, pronator teres, flexor carpi radialis, and supinator muscles. Since extensor carpi radialis longus, pronator teres, and flexor carpi radialis muscles cannot be sacrificed in this particular setting, the brachioradialis muscle was considered. The procedure required a free tendon graft, and since the palmaris longus muscle is paralyzed in such a patient, its tendon was naturally taken.

Sensory Recovery

One important aspect “neglected” in the two featured cases is the sensation reconstruction in the ulnar aspect of the hand. We focused on motor reconstruction by nerve transfer and tendon transfer techniques, anticipating that, given sufficient time, the protective sensibility of the hand would be regained through a self-compensatory mechanism (for example, takeover by the median or radial nerve). However, during the whole follow-up process (4.5 years in Case 1 and >3 years in Case 2), sensation in the ring and little fingers and the ulnar aspect of the hand did not improve (note the skin ulcer in the pulp finger in Figs. 6C and 7). This evidence may confirm that the injury in both cases was preganglionic, apart from the signs positive for Horner syndrome, physical examination findings, and electrophysiological results. In a more comprehensive surgical plan for C7–T1 brachial plexus palsies, protective sensibility in the ulnar aspect of the hand can be achieved by end-to-side neurorrhaphy of the median nerve and the sensory branches of the ulnar nerve or by neurotization of the lateral antebrachial cutaneous nerve to the dorsal branch of the ulnar nerve.7

Fig. 7. Case 2. Photographs showing the sensory deficits more than 3 years after injury. Sensibility in the ring and little finger and ulnar aspect of the hand did not improve (slash marks). Sensibility in the ulnar aspect of the forearm (dots) was decreased.

Thumb Opposition

Since nerve repair is unlikely to succeed in restoring thumb opposition, we turned to tendon transfer techniques. In a patient with C7–T1 palsy, the intact functioning muscles in the forearm include the brachioradialis, extensor carpi radialis longus, pronator teres, flexor carpi radialis, and supinator muscles. Since extensor carpi radialis longus, pronator teres, and flexor carpi radialis muscles cannot be sacrificed in this particular setting, the brachioradialis muscle was considered. The procedure required a free tendon graft, and since the palmaris longus muscle is paralyzed in such a patient, its tendon was naturally taken.

Sensory Recovery

One important aspect “neglected” in the two featured cases is the sensation reconstruction in the ulnar aspect of the hand. We focused on motor reconstruction by nerve transfer and tendon transfer techniques, anticipating that, given sufficient time, the protective sensibility of the hand would be regained through a self-compensatory mechanism (for example, takeover by the median or radial nerve). However, during the whole follow-up process (4.5 years in Case 1 and >3 years in Case 2), sensation in the ring and little fingers and the ulnar aspect of the hand did not improve (note the skin ulcer in the pulp finger in Figs. 6C and 7). This evidence may confirm that the injury in both cases was preganglionic, apart from the signs positive for Horner syndrome, physical examination findings, and electrophysiological results. In a more comprehensive surgical plan for C7–T1 brachial plexus palsies, protective sensibility in the ulnar aspect of the hand can be achieved by end-to-side neurorrhaphy of the median nerve and the sensory branches of the ulnar nerve or by neurotization of the lateral antebrachial cutaneous nerve to the dorsal branch of the ulnar nerve.7
Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper. The following grants funded this study: Grant No. 124119a1001 from the Science and Technology Commission of Shanghai Municipality (STCSM), Grant No. 81371374 from the National Natural Science Foundation of China, and a grant for clinical and basic research of brachial plexus injury from the Chinese Ministry of Health.

Author contributions to the study and manuscript preparation include the following. Conception and design: Dong. Acquisition of data: Zhang. Analysis and interpretation of data: Zhang. Drafting the article: Zhang. 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: Dong. Study supervision: Gu.

References


Manuscript submitted March 27, 2013. Accepted July 22, 2014.

Portions of this work were presented at the XVII International Symposium on Brachial Plexus Surgery held in Lisbon, Portugal, on May 20, 2011, and the III Sino-European Meeting on Brachial Plexus Surgery held in Milan, Italy, on September 15, 2012. Please include this information when citing this paper: published online August 29, 2014; DOI: 10.3171/2014.7.JNS13594.

Supplemental online information:

Address correspondence to: Zhen Dong, M.D., Ph.D., Department of Hand Surgery, Huashan Hospital, Fudan University Medical Center, 12 Wu Lu Mu Qi Zhong Rd., Shanghai 200040, China. email: zhendong@swk.shmu.edu.cn.