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ORIGINAL ARTICLE

The prerequisites and clinical outcomes of ipsilateral C7 nerve root transfer to the upper trunk for adult C5-C6 brachial plexus injuries

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Abstract

Purpose Although ipsilateral C7 nerve transfer is used for the treatment of C5-C6 brachial plexus injuries, accurately evaluating the functional quality of the donor nerve (ipsilateral C7 nerve root) is difficult, especially when the C7 nerve root is slightly injured. The purpose of this study was to determine the indicators to evaluate the quality of the ipsilateral C7 nerve and assess the clinical outcomes of this procedure.

Methods This study employed the following three indicators to assess the quality of the ipsilateral C7 nerve: (1) the muscle strength and electrophysiological status of the latissimus dorsi, triceps brachii, and extensor digitorum communis; (2) the sensibility of the radial three digits, especially the index finger; and (3) the intraoperative appearance, feel and electrophysiological status of the ipsilateral C7 nerve root. Transfer of the ipsilateral C7 nerve root to the upper trunk was implemented only when the following three tests were conducted, the criteria were met, and the clinical outcomes were assessed in eight patients with C5-C6 brachial plexus injuries.

Results Patients were followed-up for an average of 90 ± 42 months. At the final follow-up, all eight patients achieved recovery of elbow flexion, with five and three patients scoring M4 and M3, respectively, according to the Medical Research Council scoring. The shoulder abduction range of motor recovery averaged 86 ± 47° (range, 30°-170°), whereas the shoulder external rotation averaged 51 ± 26° (range, 15°-90°).

Conclusion Ipsilateral C7 nerve transfer is a reliable and effective option for the functional reconstruction of the shoulder and elbow after C5-C6 brachial plexus injuries when the three prerequisites are met.

Keywords Brachial plexus · Nerve transfer · Ipsilateral C7 nerve root · Upper trunk

Introduction

In C5-C6 brachial plexus injuries, the paralysis of shoulder and elbow function is common, and hence the restoration of elbow flexion, shoulder abduction and shoulder external rotation is of great importance and priority. By far, the strategy usually adopted is the triple nerve transfers [1, 15], which involves the transfer of partial ulnar nerve to the biceps motor branch [17], spinal accessory nerve (SAN) to the suprascapular nerve [20] and nerve from the long head of triceps to the anterior branch of the axillary nerve [14, 22].

In 2003, Gu first proposed transfer of the ipsilateral C7 (IC7) nerve root to the upper trunk in four patients with C5-C6 brachial plexus injuries [10]. This procedure was safe and did not cause permanent functional deficits for the function of the C7 nerve root could be compensated by the lower trunk [5, 11–13, 21, 23]. Since the C7 nerve root is compensable, an accurate evaluation of the functional quality of the

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donor nerve (the IC7 nerve root) is difficult, especially when the C7 nerve root is slightly injured, which limits the clinical application of this procedure.

Therefore, in the present study, we utilised the following indicators to determine whether the IC7 nerve root was healthy enough to provide adequate motor axons: (1) muscle strength and preoperative electrophysiological status of the latissimus dorsi, triceps brachii, and extensor digitorum communis; (2) sensibility of the radial three digits, especially the index finger; and (3) intraoperative appearance, feel and electrophysiological test of the IC7 nerve root. The clinical outcome of the IC7 nerve root transfer was evaluated in a series of eight patients with C5-C6 brachial plexus injuries when three prerequisites were met.

Methods

Patients

This study included eight patients (seven men and one woman) with C5-C6 brachial plexus injuries between 2011 and 2019. The average patient age was 31 ± 9 years (range, 20–43 years). The average interval between injury and surgery was 3.5 ± 2 months (range, 1–8 months). All patients were right-hand dominant, and the injuries affected the dominant upper extremity in four patients and the non-dominant arm in four patients. The mechanisms of injury included motorcycle accidents (3/8), neck stab injuries (3/8), traffic accidents (1/8), and falls (1/8). None of the patients had spinal cord injury. Three of eight patients (case #2, case #4 & case #7) had clavicle fractures.

All the patients sustained paralysis of shoulder abduction, elbow flexion and shoulder external rotation. Preoperative electromyography revealed total denervation of the muscles innervated by the C5 and C6 nerve roots. The lower trunk was undamaged according to the physical examination and electrophysiological tests. Magnetic resonance imaging and myelography were not used routinely in our unit. The diagnosis of C5-C6 nerve root injuries was confirmed using standard brachial plexus surgical exploration. Meanwhile, two patients (case 4&5) were confirmed to have injuries to the SAN and phrenic nerve.

Preoperative evaluation

All patients underwent serial physical examinations and electromyographic testing. The IC7 nerve root transfer procedure was considered when the following criteria were met: (1) the muscle strength of the latissimus dorsi, triceps brachii, and extensor digitorum communis must be at least M4 according to the Medical Research Council scoring; (2) absence of numbness or pain in the radial 3 digits, especially the index finger and no detection of hyperalgesia or hypoalgesia; and (3) preoperative electromyographic testing showed the normal motor unit potential of the latissimus dorsi, triceps brachii, and extensor digitorum communis without electrophysiological signs of denervation, such as positive sharp waves or fibrillation potential.

Surgical technique

The patient was placed in the supine position under general anesthesia. A supraclavicular incision was made for the exposure and exploration of the five brachial plexus nerve roots. Avulsed dorsal ganglions of the C5 and C6 nerve root or severe scar tissue around the intervertebral foramina were detected. Intraoperative electrophysiological tests also revealed the absence of sensory-evoked potentials in the C5 and C6 nerve root. After confirming the injuries of the C5 and C6 nerve root, the quality of the IC7 nerve root was evaluated again through appearance and intraoperative electrophysiological tests. The transfer of the IC7 nerve root was performed only when the (1) appearance of the IC7 nerve root was normal and the feel was soft when the nerve was touched, (2) the sensory-evoked potential of the IC7 nerve root was normal in terms of the wave shape, latency, and amplitude when stimulated, and (3) compound muscle action potential recorded in the latissimus dorsi, triceps brachii, and extensor digitorum communis was normal when the IC7 nerve root was stimulated. The upper trunk was cut after the C5 and C6 nerve root merged. The IC7 nerve root was cut before it was split into the anterior and posterior division of the middle trunk (Fig. 1a). The entire IC7 nerve root was sutured directly to the upper trunk using a 9–0 nylon suture (Fig. 1b). Meanwhile, the SAN was transferred directly to the suprascapular nerve in six cases. After surgery, the affected limb and neck was immobilized for 4 weeks.

Functional recovery assessment

Elbow flexion was evaluated using the British Medical Research Council grading system (range, M0-M5). The motion range of shoulder abduction and external rotation was evaluated using goniometry. The angle of external rotation was measured with the shoulder fully internally rotated and the forearm placed transversely over the abdomen so as not to miss any degree of recovery [1].

Results

Patients were followed-up for an average of 90 ± 42 months (range, 44–147 months). Postoperatively, the muscle strength of the latissimus dorsi, triceps brachii, and extensor digitorum communis decreased slightly compared with

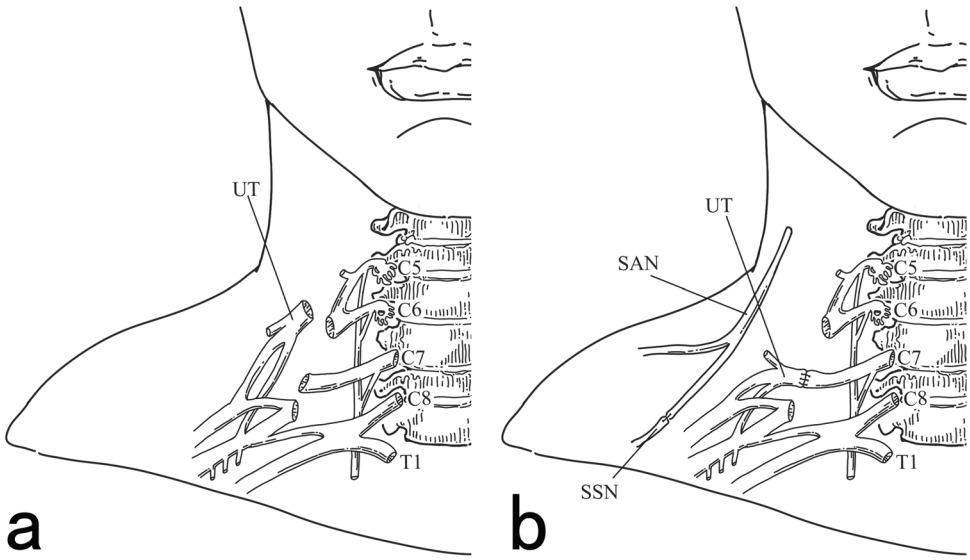

Fig. 1 Drawing of ipsilateral C7 nerve transfer. **a** The upper trunk (UT) was cut after the C5 and C6 nerve root merged. The ipsilateral C7 nerve root was cut before it was split into the anterior and posterior division of the middle trunk. **b** The ipsilateral C7 nerve root was sutured directly to the UT. Meanwhile, the spinal accessory nerve (SAN) was transferred to the suprascapular nerve (SSN)

the preoperative grade. However, it recovered to normal in all cases 3–6 months postoperatively. Numbness in the radial 3 digits, especially in the index finger, occurred in all cases; however, the protective sensation was preserved. The zone of numbness gradually narrowed and disappeared within 6 months in four patients, but was still present in the other four patients. None of the patients complained of new pain.

Bicep reinnervation, detected by electrophysiological testing occurred 6–9 months postoperatively. The first clinical sign of elbow flexion recovery was noticed 9–12 months postoperatively. At the final follow-up, all patients achieved recovery of elbow flexion, with five and three patients scoring M4 and M3, respectively.

The first recovery of shoulder abduction was observed at 9–15 months postoperatively. At the final follow-up, the shoulder abduction range of motor recovery averaged $86 \pm 47°$ (range, 30°-170°), whereas the external rotation was measured from full internal rotation averaged $51 \pm 26°$ (range, 15°-90°). Two patients (case 4&5) with SAN and phrenic nerve injuries recovered shoulder abduction at 30–35° and external rotation at 15°. The other six patients who underwent combined nerve transfer achieved recovery of shoulder abduction with a mean of $104 \pm 41°$ (range, 60°-170°). Furthermore, the angle of shoulder external rotation in these 6 patients averaged $63 \pm 18°$ (range, 30°-90°) (Table 1, Fig. 2).

Discussion

With regard to C5-C6 brachial plexus injuries, the original treatment was extra-plexual neurotization. Alternative donor nerves include the SAN [20], phrenic nerve [7] and intercostal nerve [6]. Since the proposal of intra-plexual neurotization, several healthy donor nerves originating from the middle or lower trunk have been used for shoulder and

Table 1 General data and postoperative functional recovery of the 8 patients

Case	Age (years)	Sex	Affected side	Cause	Preoperative delay (months)	Follow-up (months)	Elbow flexion strength	Shoulder abduction degree (°)	Shoulder external rotation degree (°)
1	40	Male	Right	Motorcycle accident	6	147	M4	85	60
2	20	Male	Left	Falling injury	8	140	M3	60	30
3	20	Female	Left	Neck stab injury	1	139	M4	155	90
4*	43	Male	Right	Traffic accident	2	85	M3	30	15
5*	25	Male	Right	Neck stab injury	3	65	M3	35	15
6	41	Male	Left	Neck stab injury	3	52	M4	170	70
7	27	Male	Right	Motorcycle accident	3	46	M4	70	55
8	31	Male	Left	Motorcycle accident	2	44	M4	90	70

*Case 4&5 were confirmed to have injuries to the spinal accessory nerve and phrenic nerve

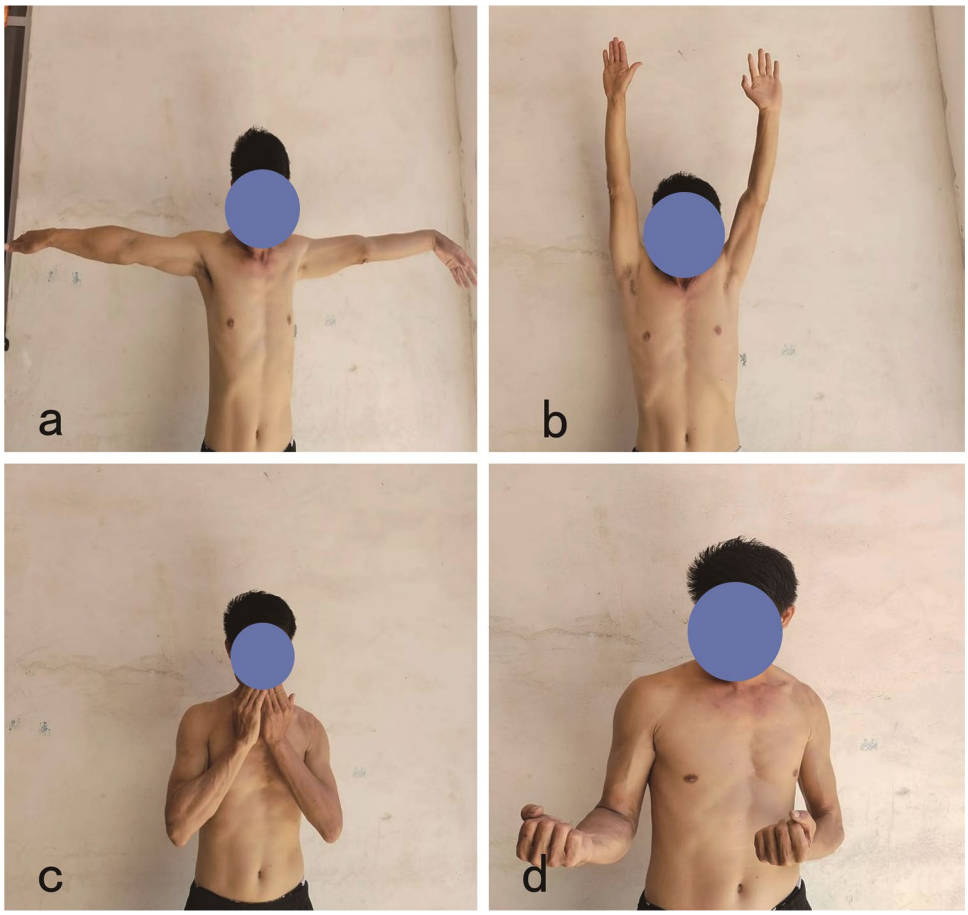

Fig. 2 Functional recovery in patient 6 (left side). **a** & **b** Shoulder abduction recovered to 170°. **c** Elbow flexion recovered to M4 grade. **d** Shoulder external rotation recovered to 70°

elbow function reconstruction after upper trunk injury, such as the medial pectoral nerve [4, 18], thoracodorsal nerve [16, 19], fascicles of the ulnar nerve [17], and triceps long head branch [14, 22].

Another intra-plexual nerve, the IC7 nerve root was first proposed by Gu in 2003 for the restoration of shoulder and elbow function in C5-C6 brachial plexus injuries [10]. Compared with the above mentioned donor nerves, the C7 nerve root has more myelinated nerve fibers (mean 23,781 fibers) [3], thus providing sufficient proximal power. Additionally, transfer of the IC7 nerve root could be performed in one incision accompanied by brachial plexus exploration and transfer of the SAN, resulting in a less traumatic operation and better postoperative incision appearance.

The rationale for this procedure is that the function of the C7 nerve root is compensated; therefore, its section would not cause permanent functional damage [5, 11–13, 23]. Rat experiments have indicated that the nerve fibers of the lower trunk can compensate for the function of the C7 nerve root through motor endplate regeneration, hence avoiding further impairment of the injured upper limb after IC7 nerve transfer [21]. In the present study, the muscle strengths of the latissimus dorsi, triceps brachii, and extensor digitorum communis recovered to normal levels in all cases, with a slight temporary decrease after the procedure. Therefore, this procedure was considered safe.

Since the function of the C7 nerve root could be compensated, it was difficult to evaluate the quality of the C7 nerve root as a donor source. In addition, a slight injury to the C7 nerve root is commonly accompanied by C5-C6 brachial plexus injuries, presenting more difficulty for surgeons to decide on the suitability of the C7 nerve root for nerve transfer. A previous electrophysiological study revealed the maximum amplitudes of latissimus dorsi, triceps brachii and extensor digitorium communis were recorded when the C7 nerve root was stimulated; hence, these three muscles were regarded as representative muscles of C7 [9]. Preoperative physical examination and electrophysiological testing was performed, focusing on these three representative muscles. However, evaluating only the muscles was not the comprehensive strategy because the latissimus dorsi is also innervated by C6 and C8, the triceps by C5, C6, C8, and T1, and the extensor digitorum communis by C8 and T1. Furthermore, considering that patients were more sensitive to sensory disturbance than to slight motor dysfunction, sensory testing was performed to account for the preoperative evaluation of the C7 nerve root. Among the 50 patients who underwent contralateral C7 nerve root transfer, the

postoperative abnormal sensation was found on the index finger in 37 cases (74%), the middle finger in 29 cases (58%), and the thumb in 19 cases (38%), indicating that the sensory territory innervated by C7 was centered on the index finger, together with the thumb and middle finger [8]. Similarly, a previous study [2] revealed normal sensibility in the hands of the majority of patients with C5-C6 injury, whereas anesthesia appeared at the radial aspect of the hands in patients with C5-C7 injury. Therefore, the sensibility of the radial 3 fingers were tested preoperatively. Finally, the quality of the IC7 nerve root was repeatedly assessed intraoperatively by visual inspection, palpation, and direct electronic stimulation.

The most common and popular strategy for treating C5-C6 brachial plexus injuries is triple nerve transfers [1, 15] that include the Oberlin procedure, SAN to suprascapular nerve, and triceps long head branch to axillary nerve. Bertelli [1] reported that all 10 patients showed recovery of full elbow flexion (7 scored M4 and 3 scored M3 +) whereas shoulder abduction and external rotation averaged 92° (range, 65°-120°) and 93° (range, 80°-120°), respectively. Leechavengvongs [15] reported full elbow flexion (13 scored M4 and 2 scored M3) recovery in all 15 patients, with the mean shoulder abduction and external rotation of 97° and 115°, respectively. In the present study, elbow flexion with at least M3 muscle strength was achieved in all patients (five and three patients scored as M4 and M3, respectively) after IC7 nerve transfer, which was similar to the results after the Oberlin procedure. However, the mean shoulder abduction (86°) and external rotation (51°) after IC7 transfer were a little inferior to those of the triple nerve transfer. We attributed these results to the motor nerve fibers of the C7 nerve root innervating the latissimus dorsi, a strong muscle for shoulder adduction and internal rotation, which was antagonistic to shoulder abduction and external rotation. We noticed two of three patients with a stab injury to the neck recovered over 150° shoulder abduction and M4 elbow flexion. One possible reason for this is that the damage to C7 neurons was more serious in traction injuries than that in cutting injuries. Therefore, triple nerve transfer is still a common option in treating C5-C6 brachial plexus injury, whereas IC7 nerve transfer could be considered an alternative method after a strict assessment of the quality of the donor source, especially when indicated for cutting injury.

Two patients with SAN and phrenic nerve injury were included. We transferred the IC7 nerve root to the entire upper trunk containing the SAN and the anterior and posterior divisions of the upper trunk. Both patients obtained good results in elbow flexion, but the recovery of shoulder function was poor. We attributed these poor results to the supraspinatus innervated by the suprascapular nerve, which plays an important role in stabilizing the scapula and initiating shoulder abduction. Compared with the direct transfer of the SAN to the suprascapular nerve, transfer of the IC7 nerve root to the entire upper trunk might cause dispersion of the donor nerve fibers and influence the recovery of the supraspinatus. In contrast, the remaining six patients with healthy SAN underwent transfer of the SAN to the suprascapular nerve and IC7 nerve root to the upper trunk and achieved relatively satisfactory shoulder function. Therefore, we recommend the transfer of the IC7 nerve root in combination with the transfer of the SAN to the suprascapular nerve when the SAN is healthy.

This study has several limitations. First, this was a retrospective study with a relatively small number of patients. Secondly, the British Medical Research Council grading system was subjective, although widely used. Additionally, the proposed preoperative and intraoperative evaluations indirectly determined the quality of the IC7 nerve root. In future studies, intraoperative frozen pathological sections of the nerve root will be helpful for a more accurate judgment.

Conclusion

IC7 nerve transfer is a reliable and effective option for the functional reconstruction of the shoulder and elbow in C5-C6 brachial plexus injuries after strict evaluation for the donor nerve.

Author Contributions Conception and design: Zhen Dong.
Acquisition of data: Bin Xu, Ying Chen and Jing-Song Tong.
Analysis and interpretation of data: Bin Xu, Ying Chen, Jing-Song Tong and Cheng-Gang Zhang.
Drafting the article: Bin Xu.
Study supervision: Zhen Dong.

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Data availability The authors confirm that the data supporting the findings of this study are available within the article.

Code availability Not applicable.

Declarations

Ethics approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Consent for publication Written informed consent for publication was obtained from all participants.

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

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