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A Clinical Analysis of Repairing the Whole Brachial Plexus Nerve Root Avulsion by Transferring C7 Nerve Root from the Uninjured Side

Boyang Wang, Yuewen Wang*

Department of Orthopaedics, Affiliated Hospital of Inner Mongolia Medical University, Inner Mongolia, China

Email address:
wangyw2019@163.com (Yuewen Wang)

*Corresponding author

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Abstract: Objective to perform a C7 transfer from the uninjured side for the patients with whole brachial plexus nerve root avulsion, conduct follow-up observations of the recovery conditions of the affected limb, and discuss the degree of the effect on the limb on the uninjured side and the mechanism. Method The 36 patients with whole brachial plexus nerve avulsion who received a C7 transfer from the uninjured side for repair by stages from January 2011-December 2011 in our hospital were selected as the objects to analyse the data of cases, carry out follow-up visits, evaluate of the limb functions on the uninjured side, and make comprehensive assessment in accordance with U.K. MRC scale for sensation and U.K. amended MRC scale for muscular strength. Result The follow-up visit results regarding the motor functions of the affected limb have indicated that there were 2 patients with effective recovery of supraspinatus muscular strength, 2 patients with effective recovery of deltoid muscular strength, 6 patients with effective recovery of biceps brachii muscular strength, 7 patients with effective recovery of triceps brachii muscular strength, 4 patients with effective recovery of extensor carpi muscular strength, and 5 patients with effective recovery of flexor carpi and flexor digitorum muscular strength. There were 7 patients whose latissimus dorsi muscular strength reached M5-, 7 patients whose triceps brachii muscular strength reached M5-, and 10 patients whose extensor digitorum muscular strength reached M5- 6 months after operation. There were 3 patients whose limb on the uninjured side reached Sensation Grade S4, 12 patients whose limb on the uninjured side reached Sensation Grade S3+, 11 patients whose limb on the uninjured side reached Sensation Grade S3, and 10 patients whose limb on the uninjured side reached Sensation Grade S2 3 days after operation. The sensory functions of the majority of the patients recovered to S4 and their two-point discrimination approximately recovered to normal at the follow-up visit 1 year after operation. Conclusion Repair with C7 transfer from the uninjured side is currently an effective and feasible method to repair the functions of the affected limb in brachial plexus nerve root avulsion.

Keywords: Brachial Plexus Nerve, C7 Nerve Root, Nerve Transfer, Therapeutic Effect

1. Background

Brachial plexus nerve injuries are primarily caused by various crushing injuries, impact injuries, or injuries directly by sharp instruments. Whole brachial plexus nerve root avulsion is an extremely severe injury. The damaged nerves are not able to be repaired directly in the spinal canal and even anastomosis is not able to achieve self-repair. It is still one of the difficult problems in the field of peripheral nerve injury repairing and it becomes more difficult to deal with particularly when complicated with such injuries as nervus phrenicus, intercostal nerve, which would lead to limited dynamic nerve source [1]. At present, multi-group nerve transfer repair is the generally accepted most effective method for recovering the innervation of the affected limb and the common donor nerves include nervus phrenicus, accessory nerve, intercostal nerve, and motor branch of cervical plexus [2]. Chuang et al. repaired the median nerve by transferring C7

nerve root from the uninjured side and successfully repaired the palm sensation and finger flexion of the affected limb [3]. No long-term functional effect arises on the uninjured side after the C7 nerve root on the uninjured side is cut due to the fact that it contains approximately 18000-40000 medullated fibers, which provide a powerful dynamic nerve source for the nerve transfer and form a middle trunk separately [4]. Currently, the surgical method has been widely applied clinically. However, in some reports, it has been discovered that dysfunction and neuropathic pain occurred to the limb on the uninjured side after the C7 nerve root was incised from the uninjured side and the influence degree has been reported different in various regions [5]. The research aims to conduct a retrospective analysis of the therapeutic effect of repairing the whole brachial plexus nerve root avulsion by clinical application of the C7 nerve root transfer from the uninjured side.

2 Material and Methods

2.1. General Data

36 patients who had their whole brachial plexus nerve root avulsion repaired by C7 nerve root transfer from the uninjured side in our hospital from January 2011 to December 2011 were selected. 22 males and 14 females; aged 18-62 years and 38.2 years on average; 17 patients with the right side injured and 19 patients with the left side injured; surgeries occurred 1-6 months after injury and 2.6 months on average; the post-operation follow up visit lasted for 24 months.

2.2. Diagnosis

36 patients were preliminary diagnosed with traumatic brachial plexus C5-T1 avulsion based on a pre-operative clinical examination, electromyographic examination, and MRI examination and were further demonstrated by a surgical exploration and intraoperative myoelectric and conduction tests. The Horner syndrome was positive in patients; the somatosensory evoked potential SSEP was not detected; no significant myoelectric response was observed when the distal muscle of the nerve root was stimulated. It is thus clear that the injury of the cases in the group was identified as a postganglionic injury, i.e. root avulsion [6]. See Figure 1.

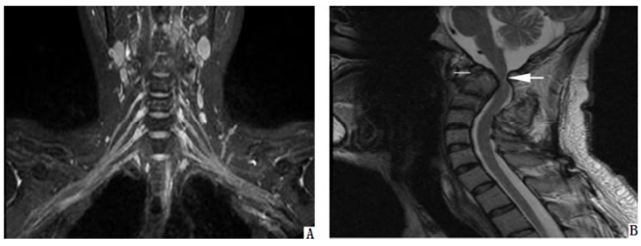

Figure 1. *MRI Schematic Diagram for Brachial Plexus Nerves.*

Legend: A. normal brachial plexus nerves; B. damaged brachial plexus nerves.

2.3. Selection of Bridging Nerves

Two nerve transfer methods were used for the cases of the group. The free cutaneous nerves (sural nerves) served the bridging nerves when repairing superior trunk by C7 transfer from the uninjured side. Both ends anastomosed with the C7 nerve root on the uninjured side and the receptor nerves during the one-stage operation; the ulnar nerves of the retrograde superior ulnar collateral artery served as the bridging serves when repairing the median nerve, musculospiral nerve, or median nerve and triceps brachii muscular branch. The operation was performed in two stages. The position for nerve regeneration was determined by the Tinel sign along the bridging nerves at the interval between the two operations. The second operation was performed when the nerve grew to the anterior axilla region on the affected side. The interval between the two operations was 4-9 months and 7.2 months on average.

2.4. Cutting and Grouping of C7 on the Uninjured Side

In the cases of the group, the cutting mode for the C7 nerve on the uninjured side was selected based on the diameter of the transplanting nerve. The whole trunk of C7 on the uninjured side would be cut if the diameter of the transplanting nerve was large and only the posterior divisions of the C7 on the uninjured side were cut when the transplanting nerve was thin.

In the research cases, 17 patients who received the whole root transfer of the C7 nerve root from the uninjured side were selected as Group A and 19 patients who received separate transfer of posterior divisions of the C7 nerve root from the uninjured side were selected as Group B. See Figure 2.

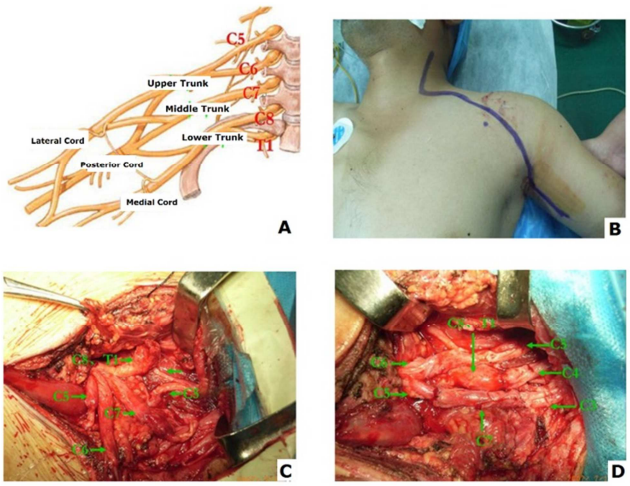

Figure 2. *Cutting and grouping of C7 on the uninjured side.*

Legend: A. schematic diagram for brachial plexus nerves; B. exploring the incision of patient; C. Whole brachial plexus avulsion was observed during operation. D. after repair of brachial plexus.

2.5. Postoperative Management

External fixation of affected limbs was performed for all patients to prevent any traction of the nerve anastomosis site. The fixation was removed and exercise related to motion of the

limb on the uninjured side was performed after 4 weeks. The exercise primarily included muscle training relevant to the C7 nerve root, e.g. shoulder adduction (latissimus dorsi contraction), elbow stretching exercise (triceps brachii contraction), wrist stretching and finger stretching (extensor carpi and extensor digitorum contraction) etc., which promoted nerve regeneration and deferred degeneration of the end plate of the nerve muscle thus achieving better recovery results.

2.6. Follow-up Visits and Evaluation

All of the 36 patients obtained long-term follow-up visits with respect to sensation of affected limb and recovery of motor functions and the follow-up visits lasted for 24 months.

The content of follow up visit for sensation included tactile sense, sense of pain, and two-point discrimination and they were evaluated and graded referring to the British Medical Research Council (MRC) Scale for Sensation (SO-S4) [7]. At the follow-up visit for motor functions, the muscular strength of the target muscle innervated by relevant nerves served the index and an evaluation was made referring to the British Medical Research Council (MRC) Scale for Muscular Strength [8]. E.g.: The recovery would be evaluated by detecting the muscular strength of flexor carpi and flexor digitorum after the median nerve was repaired; the recovery would be evaluated by detecting the muscular strength of triceps brachii and extensor carpi after the musculospiral nerve was repaired.

At follow-up visits for the sensation and motor functions of the limb on the uninjured side, the data of cases demonstrated that all of the 36 patients in the group experienced abnormalities in sensation of the limb on the uninjured side after operation. The motor functions of the uninjured side were examined 2 weeks after operation to exclude the effect of post-operation pain on the examination of motor functions. At the follow-up visit 6 months after operation, the muscular strength of latissimus dorsi, triceps brachii, and extensor digitorum was detected. The effect of C7 transfer from the uninjured side on the long-term motor functions of the limb on the uninjured side was evaluated by reference to the relevant standard [9].

2.7. Data Statistics

A rank sum test was conducted for the scale of the sensation of the limb on the uninjured side 3 days after operation and 1 year after operation using the SPSS 13.0 software. A Chi-Square test was conducted for the recovery rate of two-point discrimination of the pulp of the fingers on the uninjured side at different times after operation. The value was 0.05 in the inspection standard.

3 Results

3.1. Follow-up Visit for Motor Functions

In the cases of the group, the recovery of post-operation motor functions was evaluated and graded as follows: Poor M0-M2, Moderate M2+-M3, Good M3+-M4-, Excellent M4-M5-.

In accordance with the above evaluation criteria, the follow-up visit for the motor functions of affected limbs indicated that there were 2 patients with effective recovery of supraspinatus muscular strength and the recovery rate was 66.67% but there was no excellent or good cases. There were 2 patients with effective recovery of deltoid muscular strength and the recovery rate was 40% but there were no excellent and good cases. There were 6 patients with effective recovery of biceps brachii muscular strength and the recovery rate was 75%, among which 4 patients were with excellent and good recovery. There were 7 patients with effective recovery of triceps brachii muscular strength and the recovery rate was 63.64%, among which 4 patients were with excellent and good recovery. There were 4 patients with effective extensor carpi muscular strength and the efficiency rate was 40% without any excellent or good cases. There were 5 patients with effective recovery of flexor carpi and flexor digitorum muscular strength and the recovery rate was 71.43%, among which there were 2 excellent and good cases. See Table 1.

Table 1. *Results of Recovery of Post-Operation Motor Functions at Follow-Up Visits.*

	Poor (M0-M2)	Moderate (M2+-M3)	Good (M3+-M4)	Excellent (M4+-M5)
Supraspinatus	1	2	0	0
Deltoid	3	2	0	0
Biceps Brachii	2	2	3	1
Triceps Brachii	4	3	2	2
Extensor Carpi	6	4	0	0
Flexor Carpi and Flexor Digitorum	2	3	1	1

3.2. Follow-up Visit for Sensation Recovery

In Group B, 9 patients had their median nerves repaired. There were 6 patients whose sensation innervation area of the median nerve reached S2 and 2 patients whose sensation innervation area of the median nerve reached S1. 1 patient showed no signs of recovery.

3.3. Results of Follow-up Visits for the Motor Functions of the Limb on the Uninjured Side 6 Months After Operation

There were 7 patients whose latissimus dorsi muscular strength reached M5-(3 in Group A and 4 in Group B). There were 7 patients whose triceps brachii muscular strength reached M5- (4 in Group A and 3 in Group B). There were 10

patients whose extensor digitorum muscular strength reached M5- (5 in Group A and 5 in Group B). There was 1 patient (Group A) whose muscular strength of the whole extensor digitorum and extensor hallucis longus reached M0 and no significant recovery was discovered at the follow-up visit after 2 years. See Table 2.

Table 2. *Changes in Muscular Strength of Limb on the Uninjured Side.*

	Latissimus Dorsi			Triceps Brachii			Extensor Digitorum			
	M5	**M5-**	**M4**	**M5**	**M5-**	**M4**	**M5**	**M5-**	**M4**	**M0**
Group A (n=17)	14	3	0	13	4	0	11	5	0	1
Group B (n=19)	15	4	0	16	3	0	14	5	0	0

3.4. Results of Follow-up Visits for Sensation of the Limb on the Uninjured Side After Operation

2 patients complained of no significant changes in sensation after operation and all of the 34 patients complained of transient sensations, which were manifested by feeling of numbness, occasional swelling and pain without neuralgia. The incidence rate was 100% in Group A and 89.47% in Group B.

3 days after operation, there were 3 patients whose sensation grade of the limb on the uninjured side reached S4 (1 in Group A and 2 in Group B), 12 patients whose sensation grade of the limb on the uninjured side reached S3+ (3 in Group A and 9 in Group B), 11 patients whose sensation grade of the limb on the uninjured side reached S3 (7 in Group A and 4 in Group B), 10 patients whose sensation grade of the limb on the uninjured side reached S2 (6 in Group A and 4 in Group B); the effect on the sensation of the limb on the uninjured side of the patient was minor; $P<0.05$ indicated a significant difference. See Table 3.

Table 3. *Changes in Sensation of Limb on the Uninjured Side 3 Days after Operation.*

	S4	**S3+**	**S3**	**S2**
Group A (n=17)	1	3	7	6
Group B (n=19)	2	9	4	4

At the follow-up visit 1 year after operation, for the majority of the patients, the sensation functions reached S4 and the two-point discrimination was approximately normal; 13 patients experienced a long-term sensation abnormality (6 in Group A and 7 in Group B); there were 23 patients whose sensation grade of the limb on the uninjured side reached S4 (11 in Group A and 12 in Group B), 6 patients whose sensation grade of the limb on the uninjured side reached S3+ (2 in Group A and 4 in Group B), 5 patients whose sensation grade of the limb on the uninjured side reached S3 (3 in Group A and 2 in Group B), and 2 patients whose sensation grade of the limb on the uninjured side reached S2 (1 in Group A and 1 in Group B). $P>0.05$ indicated no significant difference. See Table 4.

Table 4. *Changes in Sensation of Limb on the Uninjured Side 1 Year after Operation.*

	S4	**S3+**	**S3**	**S2**
Group A (n=17)	11	2	3	1
Group B (n=19)	12	4	2	1

The results of follow-up visits for the two-point discrimination of the pulp of the finger on the uninjured side after operation indicated that there were 11 patients (5 in Group A and 6 in Group B) whose two-point discrimination of the pulp of the finger on the uninjured side returned to approximately normal 1 week after operation, 16 patients (8 in Group A and 8 in Group B) whose two-point discrimination of the pulp of the finger on the uninjured side returned to approximately normal 2 weeks after operation, 21 patients (10 in Group A and 11 in Group B) whose two-point discrimination of the pulp of the finger on the uninjured side returned to approximately normal 4 weeks after operation, 27 patients (14 in Group A and 13 in Group B) whose two-point discrimination of the pulp of the finger on the uninjured side returned to approximately normal 8 weeks after operation, and 33 patients (16 in Group A and 17 in Group B) whose two-point discrimination of the pulp of the finger on the uninjured side returned to approximately normal 16 weeks after operation. The tests at different times showed $P>0.05$ indicating no significant difference. See Table 5.

Table 5. *Changes in Two-Point Discrimination on the Uninjured Side after Operation.*

	1 Week	**2 Week**	**4 Week**	**8 Week**	**16 Week**
Group A (n=17)	5	8	10	14	16
Group B (n=19)	6	8	11	13	17

4. Discussion

The brachial plexus nerves comprise most of the anterior branch of C5-8 nerves and the anterior branch of the first thoracic nerve, which pass through the scalene fissure and enter the axilla through the rear part of the axilla. The nerve roots constituting the brachial plexus first converge into upper, middle and lower trunks; each trunk then splits into anterior and posterior divisions; the anterior divisions of the upper and middle trunks converge into the lateral cord and the anterior divisions of the lower trunk converge into the medial cord; the posterior divisions of the three trunks converge into the the posterior cord; the lateral cord, medial cord, and the post cord surround the axillary artery [10]. The brachial plexus branches are distributed in musculi membri superioris of the chest, muscles of shoulder, superficial back muscles (excluding trapezius), arm, forearm, muscles of hand, joints, bones, and

skins [11]. Brachial plexus concentrates in the rear of the midpoint of the clavicle. It is located superficially and can be felt easily. It usually serves as block anesthesia in brachial plexus [12].

Song has opined that the ipsilateral dynamic nerve should still be preferred when repairing the damaged to brachial plexus nerves by using nerve tranfer [13]. Repair by transferring C7 nerve root from the uninjured side should comply with the following surgical indications: (1) The patient is complicated with a severe cervicothoracic trauma on the affected side and it is impossible to use the ipsilateral accessory nerves, phrenic nerves, and intercostal nerves; (2) The nerve fibers on the affected side available for transfer are insufficient in either quantity or quality and do not meet the demand for reconstruction of the functions of the affected limb; (3) No significant functional recovery occurs after the affected limb is repaired by transferring the ipsilateral nerves; (4) As a standby for part of multiple groups of nerve transfer, any group of nerve transfer can be substituted timely once it fails [14-16].

The C7 nerve root contains 25000 myelinated fibers on average, which provides a rich dynamic source for reconstructing the functions of the whole injured brachial plexus [17-18]. Many studies have reported that the surgical method is demonstrated to achieve satisfactory clinical results and have no significant effect on the functions of the uninjured side [19-20]. Theoretically, treatment of brachial plexus nerve injury by transferring the C7 from the uninjured side has the following advantages: (1) A number of myelinated nerve fibres make it possible to selectively reconstruct multiple groups of injured nerves and contribute to growth of nerve fibres on the distal end of the affected limb; (2) A very high level of innervation is present between the C7 nerve root and C6 and C8 nerve roots and complete or partial cut of the C7 nerve root has no significant effect on the uninjured side, which is relatively safe; (3) The probability of separate injury of the C7 nerve root (middle trunk) is very low in primary traumas [21-23]. However, the disadvantageous factors of the surgical method should not be ignored. Its widely application is restricted by a long growth distance of the nerve fibres, possible dysfunctions that may cause to the limb on the uninjured side etc.

It has been reported that the effect of repairing the median nerve by transferring C7 from the uninjured side is superior to repairing other nerve fiber bundles [24]. Wang et al. have reported 5 of the 8 patients who had their median nerves repaired by transferring the whole C7 nerve root from the uninjured side recovered and their muscular strength of flexor carpi and flexor digitorum reached better than M3 at a more than two years' follow-up visit [25]. Aichaoui et al. have reported based on statistics of a large sample that among the 21 patients who had their median nerves repaired by transferring partial C7 nerve root from the uninjured side and obtained a more than 3 years' follow-up visit, 6 (29%) recovered the muscular strength of flexor carpi and flexor digitorum to an extent of M3 and 17 (81%) recovered the sensation of the sensation area of the median nerve to an extent better than S2 [26]. Ali et al. have reported that among the 96 patients who had their median nerves repaired by transferring the anterior division of C7 from the uninjured side, at a more than 3 years' follow-up visit, 29% recovered their muscular strength of flexor carpi to an extent better than M3 and 21% recovered their muscular strength of flexor digitorum to an extent better than M3. The motor functions of the forearm recovered unsatisfactorily but the satisfaction degree of the sensation functions reached as high as 83% [27].

5. Conclusion

It is reasonable to repair the upper trunk injury by transferring the C7 nerve root from the uninjured side during treatment of brachial plexus nerve root avulsion if no effective dynamic nerve source is available due to simultaneous complication of nervus phrenicus and accessory nerve paralyses. Synchronous transferring may be used to recover the supraspinatus, infraspinatus, deltoid, and biceps brachii; the musculospiral nerve (nerve tract of triceps brachii) may be repaired by transfer to recover the elbow extension, wrist extension, and finger extension functions. Among the patients of the group obtained follow-up visits, 4 recovered their muscular strength of biceps brachii to an extent better than M3+, 4 recovered their muscular strength of triceps brachii to an extent better than M3+, and none recovered their muscular strength of supraspinatus, deltoid, and extensor carpi to an extent better than M3+. Compared with the previous reports, the recovery rate of the biceps brachii functions in patients of the group is basically similar to the data reported by Bertelli et al. but the recovery conditions of muscular strength of supraspinatus, deltoid, triceps brachii, and flexor carpi are considerably different [28]. In the patients of the group obtained follow-up visits, we have discovered that the result of repairing the biceps brachii, flexor carpi and flexor digitorum by transferring the C7 nerve root from the uninjured side is superior to that of repairing the shoulder abduction, biceps brachii, and forearm extensors. However, it is generally accepted that the musculocutaneous nerve is superior to musculospiral nerve followed by median nerve in term of the recovery rate of the motor functions of the affected side (muscular strength>Grade 3) [29-30].

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