



Comparative study of single and dual nerve transfers for repairing shoulder abduction

Feng Xiao^{1,2,3} · Xin Zhao^{1,2,3} · Jie Lao^{1,2,3} 

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Abstract

Objective The purpose of this study was to compare the effects of single and dual nerve transfer for the repair of shoulder abduction in patients with upper or upper and middle trunk root avulsion.

Methods We carried out a retrospective analysis of 20 patients with C5-C6 or C5-C7 root avulsion treated by nerve transfer in our hospital. The patients were divided into two groups according to the different operation methods. In group A, ten patients had transferred the spinal accessory nerve to the suprascapular nerve. Ten patients in group B underwent dual nerve transfer to reconstruct shoulder abduction, including the spinal accessory nerve transfer to the suprascapular nerve and two intercostal nerves or the long head of triceps nerve branch transfer to the anterior branch of the axillary nerve. There was no difference in age, preoperative interval, follow-up time, and injury type between the two groups. We used shoulder abduction strength, shoulder abduction angle, and Samardzic's shoulder joint evaluation standard as the postoperative evaluation index. Shoulder abductor muscle strength equals or above M3 was considered to be an effective recovery.

Results Of the 20 cases, 15 obtained equals or more M3 of shoulder abduction strength, and the overall effective rate was 75%. The effective rate of shoulder abduction power in group A was 60% (6/10) while group B was 90% (9/10); however, the difference was not statistically significant ($p > 0.05$). The average shoulder abduction angle was 55° (SD = 19.29) in group A and 77° (SD = 20.44) in group B; the angle was significantly better in group B than that in group A ($p < 0.05$). Based on Samardzic's standard, the excellent and good rate of group A was 90% and in group B was 50%. The difference was statistically significant ($p < 0.05$).

Conclusion For patients with nerve root avulsion of C5-C6 or C5-C7, repairing suprascapular nerve and axillary nerve at the same time is more effective than repairing suprascapular nerve alone in terms of shoulder abduction angle and excellent rate of functional recovery of the shoulder joint. Therefore, we recommend the repair of the suprascapular nerve and the axillary nerve simultaneously if conditions permit.

Keywords Brachial plexus injury · Nerve transfer · Shoulder abduction · Suprascapular nerve · Axillary nerve

Introduction

Brachial plexus injury, especially root avulsion, is difficult to treat and is under a poor prognosis. The stability and function

of shoulder and elbow joint are very important in the function of the upper limb. Therefore, reconstruction of shoulder and elbow joint in patients with brachial plexus injury should be given priority [3, 16]. Traumatic brachial plexus injury in the upper and middle trunk injury is more common which resulting in shoulder and elbow dysfunction. At present, the reconstruction of upper limb function after brachial plexus injury mainly includes nerve transfer and free functioning muscle transfers [5]. The function of the shoulder joint is mainly the function of shoulder abduction and rotation. The transfer of the spinal accessory nerve to the suprascapular nerve has been widely accepted for the reconstruction of shoulder joint function [6, 12].

According to the previous anatomical studies, the abduction of the shoulder was mainly innervated by the suprascapular nerve and the axillary nerve. It has been

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✉ Jie Lao
laojie2018@sina.com

¹ Department of Hand Surgery, Huashan Hospital, Fudan University, No. 12 Wulumuqi Road, Jing An District, Shanghai 200040, People's Republic of China

² Key Laboratory of Hand Reconstruction, Ministry of Health, Shanghai, People's Republic of China

³ Shanghai Key Laboratory of Peripheral Nerve and Microsurgery, Shanghai, People's Republic of China

reported that the transfer of the spinal accessory nerve alone to the suprascapular nerve can obtain an average of 45° of shoulder abduction while a mean of 70° of shoulder abduction could be achieved after nerve transfer to repair the suprascapular nerve and the axillary nerve simultaneously [7]. Baltzer et al. also considered that the functional recovery of the shoulder joint after transfer of the single spinal accessory nerve to repair the suprascapular nerve was unsatisfactory [1]. Leechavengvongs et al. believe that in addition to repairing the suprascapular nerve, the axillary nerve should also be repaired in order to achieve better shoulder joint function [10]. At present, the commonly used nerve to repair axillary nerve includes the intercostal nerve and the motor branch of triceps muscle [4, 11, 17]. Therefore, the purpose of this study was to compare the efficacy of repairing suprascapular nerve alone with repairing suprascapular nerve and axillary nerve simultaneously to reconstruct shoulder abduction function.

Patients and methods

Population

We carried out a retrospective analysis of 20 patients with C5-C6 or C5-C7 root avulsion from January 2014 to December 2016 at Huashan Hospital, Fudan University. All patients were diagnosed with C5-C6 or C5-C7 injury by preoperative physical examination, electromyography (EMG), radiological examination (including MRI of the brachial plexus), and intraoperative exploration. The function of shoulder abduction was reconstructed by nerve transfer in our hospital. The operative methods included spinal accessory nerve-suprascapular nerve and spinal accessory nerve-suprascapular nerve combined with intercostal nerve or the long head of triceps nerve branch-axillary nerve. The average age of 20 patients was 28.9 years (range 14 to 51), the interval between injury and operation was 5 months (range 1 to 18), and the mean follow-up time was 32.5 months (range 18 to 54). C5-C6 injury took place in 11 cases and C5-C7 injury in 9 cases.

According to the different types of surgery, 20 patients were divided into group A and group B, with 10 cases in each group. Patients in group A received the spinal accessory nerve transfer to the suprascapular nerve. In group B, in addition to receiving the transfer of the spinal accessory nerve to the suprascapular nerve, 6 patients also received transfer of the long head triceps of nerve branch to the axillary nerve and 4 patients received transfer of two intercostal nerves to the axillary nerve. According to the statistical analysis, there was no difference in age, injury type, preoperative interval, and follow-up time between group A and group B. The details are shown in Table 1.

Surgical technique

The spinal accessory nerve transfers to the suprascapular nerve: before operation, all the patient under general anesthesia and in a supine position. A transverse incision was made superior to the clavicle. The brachial plexus was exposed and C5-C6 or C5-C7 root avulsion was confirmed. The suprascapular nerve was identified at the later border of the superior trunk. Then the spinal accessory nerve was found on the anterior surface of the trapezius deep muscular fasciae and was divided distally as distal as possible. After the spinal accessory nerve was exposed, an electric was administrated to make sure its functional integrity. The spinal accessory nerve sutured to the suprascapular nerve directly without tension under an operation microscope. In our study, 9–0 sutures were used in nerve coaptation. Finally, the supraclavicular incision was closed.

Intercostal nerve transfers to the axillary nerve: The operation was carried out in a supine position with the arm abduction and the patient was also under general anesthesia. An incision was made along the midaxillary line and then to identify the intercostal nerves. We usually use of third and fourth or fourth and fifth intercostal nerves as donors. After the quality of intercostal nerve was confirmed with an electric stimulation, two intercostal nerves were sectioned distally at the level of the anterior axillary line and then guided toward the axilla. Another incision was made in the axilla, and the anterior branch of the axillary nerve was identified and dissected as proximally as possible in order to gain enough length. Two intercostal nerves were anastomosed the anterior branch of the axillary nerve directly without tension at 90° of shoulder abduction.

The long head of the triceps nerve branch transfers to the axillary nerve: After general anesthesia, the operation was carried out in a spinal position with the arm abduction. A longitudinal incision along the medial upper arm was made and extending to the axilla. Exposure of the axillary nerve was described as above. The radial nerve was identified in the medial incision of the upper arm, along the trunk of the radial nerve, the long head of triceps nerve branch muscle was identified and separated as distal as possible. The nerve to the long head of triceps then sutured to the axillary without tension.

Outcome assessment

Based on the results of the latest follow-up, the patient's shoulder abduction was evaluated. The British Medical Research Council (MRC) muscle grading scale [9] was used for evaluating the shoulder abduction strength. Return of shoulder abduction power of M3 or better was regarded as an effective recovery. The angles of shoulder abduction were recorded and expressed as mean and standard deviation. We used the

Table 1 Details of basic data of 20 patients

Case	Age (years)	Type of injury	Time interval from injury to surgery (month)	Surgical	Follow-up time (month)	Range of shoulder abduction (degree)	Motor recovery grade (MRC)	Shoulder function classification (Samardzic's criteria)
1	19	C5-C6	3	SAN-SSN LHT-AAN	18	70	M3	Good
2	42	C5-C7	5	SAN-SSN	33	85	M3	Good
3	14	C5-C6	5	ICN-AAN SAN-SSN LHT-AAN	36	90	M4	Good
4	17	C5-C7	3	SAN-SSN	29	60	M3	Good
5	19	C5-C6	3	SAN-SSN	31	100	M4	Excellent
6	21	C5-C6	5	LHT-AAN SAN-SSN	25	45	M3	Fair
7	51	C5-C6	2	SAN-SSN	30	80	M3	Good
8	24	C5-C6	4	ICN-AAN SAN-SSN	33	60	M3	Good
9	20	C5-C7	6	SAN-SSN	32	45	M2	Fair
10	24	C5-C7	4	SAN-SSN	43	90	M4	Good
11	34	C5-C7	2	SAN-SSN	45	50	M3	Good
12	33	C5-C6	2	SAN-SSN	31	85	M3	Good
13	39	C5-C6	4	SAN-SSN	30	70	M3	Good
14	40	C5-C7	5	ICN-AAN SAN-SSN LHT-AAN	54	105	M4	Excellent
15	23	C5-C7	18	SAN-SSN	35	40	M2	Fair
16	27	C5-C6	7	SAN-SSN	30	50	M3	Good
17	26	C5-C6	5	LHT-AAN SAN-SSN	28	45	M2	Fair
18	42	C5-C7	6	SAN-SSN	32	30	M2	Fair
19	28	C5-C6	4	SAN-SSN	30	80	M3	Good
20	35	C5-C7	7	ICN-AAN SAN-SSN LHT-AAN	24	40	M2	Fair

SAN spinal accessory nerve, SSN suprascapular nerve, LHT branch to long head of triceps, AAN axillary nerve, ICN intercostal nerve

criteria proposed by Samardzic et al. [11, 14] to evaluate the shoulder function; the evaluation criteria were as follows: (1) bad denoted no movement or weightless arm movement and usually no trophic changes or alterations observed on electromyographic studies; (2) fair denoted arm movement against gravity with the ability to maintain position and improvement noted with regard to trophic changes and electromyographic studies, active arm abduction up to 45°; (3) good denoted arm movement against resistance with ability to repeat movements in succession and improvement observed with regard to trophic changes and on electromyographic studies, active arm abduction greater than 45°; and (4) excellent denoted nearly normal function. Good and excellent results were considered to represent an effective recovery.

Statistical analysis

The continuous variables were expressed as mean \pm standard deviation (mean \pm SD) and categorical variables were

expressed as frequencies and percentages. Student's *t* test was used to compare the continuous data. Fisher's exact test and the Wilcoxon test were used to compare categorical data between the two groups. *p* values < 0.05 were considered significant. All statistical analysis was performed using SPSS software (version 23.0, SPSS Inc., Chicago, IL, USA).

Results

Among the 20 patients, no infection, respiratory dysfunction, and reduction of elbow extension was found.

The grade of shoulder abduction strength was summarized in Table 2. Of the 20 patients, the ultimate strength of the abductor muscle was M3 in 11 and M4 in 4; the overall effective rate was 75% (15/20). In group A, there were 5 cases achieved shoulder abduction strength of M3 and 1 case in M4, the effective rate was 60%. While in group B, there were 6 cases in M3 and 3 cases in M4 and the effective rate was

Table 2 MRC grades of shoulder abduction after operation

Groups	M0	M1	M2	M3	M4	Effective rate (%)
A	0	0	4	5	1	60
B	0	0	1	6	3	90

Fisher's exact test: $p = 0.303$

90%. However, there was no significant difference in the effective rate between the two groups ($p > 0.05$).

The angle of shoulder abduction was presented in Table 3. In the aspect of shoulder abduction angle, the average angle of group A was $55.00 \pm 19.29^\circ$ (range 30–90) while the average shoulder abduction angle of group B was $77.00 \pm 20.44^\circ$ (range 40–105). Shoulder abduction angle in group A was significantly better than that in group B ($p < 0.05$).

According to the evaluation criteria of the shoulder joint proposed by Samardzic et al., good and excellent was 11 cases and 3 cases, respectively. Overall excellent and good rate was 70% (14/20). In group A, the good and excellent grade was achieved in 5 cases and 0 cases respectively, and the excellent and good rate was 50% (5/10). Six cases and 3 cases in good and excellent grade respectively in group B, the excellent and good rate was 90% (9/10). The difference of excellent and good rate between the two groups was statistically significant ($p < 0.05$) and the details shown in Table 4.

Discussion

Previous studies has reported that axillary nerve repaired by nerve transfer cannot achieve an excellent recovery and could not be repaired, but Gillis et al. and Chu et al. reported that the repair of axillary nerve was helpful to the function of shoulder joint and should be repaired [4, 8]. In our study, although the effective motor recovery rate in the group with dual nerve transfer was higher than that in the group with single donor nerve, the difference was not statistically significant. In the aspects of angle of shoulder abduction and shoulder function evaluation of Samardzic's standard, patients transferred with the spinal accessory nerve and the suprascapular nerve had significantly better results than that patient transferred by the suprascapular nerve alone. The rate of motor recovery between the two groups was no statistical difference; we thought there were several reasons for the outcomes. Firstly, the difference could not be observed because of the small sample

size. In addition, follow-up time may also be a reason. Considering the slow growth rate of peripheral nerve, it takes some time for the muscle to recover its function after the nerve fiber grows to the target muscle. Therefore, the insufficient follow-up time may lead to the muscle contraction function not fully restored during the follow-up. Based on the anatomical study, supraspinatus muscle and deltoid muscle are the main muscles of shoulder abduction, which are innervated by the suprascapular nerve and axillary nerve respectively. In addition, the teres minor which innervated by the axillary nerve also has the partial function of shoulder abduction. Therefore, additional axillary nerve repair can increase the muscle strength and the angle of shoulder abduction. In this study, the axillary nerve was repaired by transferring of the long head of triceps nerve branch or intercostal nerve. Compared with these two donor nerves, the long head of triceps nerve branch transfer was less traumatic than intercostal nerve transfer and did not affect respiratory function after operation, so it was a recommended operation method. However, some of the radial nerve fibers come from C7 nerve roots. In some patients with C5–C7 injury, special attention should be paid to whether the elbow extensor muscle strength is normal before operation. If the strength of elbow extension is decreased preoperative, in order to avoid the limitation of elbow extension function after operation, the intercostal nerve should be selected as the donor nerve to repair the axillary nerve. In addition, if the patient has an ipsilateral rib fracture, then no intercostal nerve transfer will be performed, because a rib fracture may be accompanied by an intercostal nerve injury.

Anatomical studies have revealed that the anterior and middle deltoid muscles were innervated by the anterior division of the axillary nerve [2]. Because of the following advantages, in the operation of axillary nerve repair, we chose the anterior branch of the axillary nerve as the recipient nerve. Firstly, the number of nerve fibers in the two intercostal nerve was similar to that in the anterior axillary nerve, and the deficiency of donor nerve fibers was avoided [15, 16]. Then, the anterior branch of the axillary nerve is the motor nerve. Compared with the repair of the axillary nerve, direct repair of the anterior branch of the axillary nerve can avoid the waste of nerve fibers. Furthermore, both intercostal nerve and the long head of the triceps nerve branch can be sutured directly to the anterior branch of the axillary nerve, thus avoiding nerve transplantation, which is extremely important to improve the curative effect.

Table 3 The angle of shoulder abduction postoperative

Groups	Abduction degrees, mean (SD)	Range of abduction angle degrees
A	55.00 (19.29)	30–90
B	77.00 (20.44)	40–105

Student's *t* test: $p = 0.023$

Table 4 The grade of shoulder joint according to Samardzic's criteria

Groups	Bad	Fair	Good	Excellent
A	0	5	5	0
B	0	1	7	2

Wilcoxon test: $p = 0.030$

According to the report of Emamhadi et al., when the suprascapular nerve was repaired by the spinal accessory nerve alone, shoulder abduction strength achieved M3 or better was 63.6% [6]. In the case of shoulder abduction, although some studies concluded that the repairing of axillary nerve alone was less effective than that of suprascapular nerve repaired alone, but when the axillary nerve and the suprascapular nerve were repaired at the same time, the abductor muscle strength of the shoulder equal and over than M3 was 85.7% [13]. In the aspect of shoulder abduction angle in our study, the angle in group with dual nerve transfer was significantly larger than that in group with single nerve transfer. Gao et al. study showed that an average of 45° of shoulder abduction could be obtained when the spinal accessory nerve was transferred to the suprascapular nerve alone while an average of 70° could be achieved when the spinal accessory nerve was transferred to the suprascapular nerve combined intercostal nerve transferred to the axillary nerve [7]. Chu et al. followed up 19 patients who underwent a dual nerve transfer to reconstruct shoulder abduction for an average of 62 months, and the data suggesting that the mean shoulder abduction angle of 93.3° could be obtained [4]. In our study, the average shoulder abduction angle in the group with single nerve transfer was 55° while in the group with dual nerve transfer was 77°, which was consistent with the previous conclusions.

In our study, we used Samardzic's criteria to evaluate the postoperative shoulder function. Samardzic standard was put forward in 2002. The main assessment index was shoulder abduction muscle strength and angle [11, 14]. It was simple and convenient for clinical application and has been widely used in shoulder joint function evaluation.

There were still some shortcomings in our study. It was a retrospective study that the recall bias and selective bias existed. In addition, the sample size was small, and the popularization of conclusion needs further research. Furthermore, shoulder rotation was also very important for shoulder joint function, but it was not included in the evaluation index in this study. Also, body mass index (BMI) may be a factory, but was not included in our follow-up.

Conclusion

These limitations aside, we believe that the transfer of the spinal accessory nerve to the suprascapular nerve combined

with transferring of intercostal nerve or the long head of triceps nerve branch to the axillary nerve can obtain better shoulder joint function and greater shoulder abduction angle. For those injured in C5-C6 or C5-C7, if the donor nerve is sufficient, we recommend dual nerve transferring to repair shoulder joint function.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical 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.

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Comments

The authors reviewed their results in restoring shoulder abduction in 20 patients with upper brachial plexus injuries. 10 of the patients were treated with spinal accessory to suprascapular nerve transfers and 10 of the patients had spinal accessory to suprascapular nerve transfers along with neurotization of the anterior branch of the axillary nerve. The authors found that the double repair provided superior results. I don't think that these findings are particularly surprising to surgeons who regularly do brachial plexus repair surgery. Neurotization of the axillary nerve using a branch of the radial nerve to the long head of the triceps has been a part of the surgeon's armanentarium for some time. I did find it very interesting that the patients seem to be afforded a good result from transferring intercostal nerves to the axillary nerve. In my practice if the

patient did not have sufficient triceps strength, abduction of the shoulder was treated with a single anastomosis from the spinal accessory nerve to the suprascapular nerve. The next time I see such a patient I will supplement that single anastomosis with an intercostal to axillary nerve anastomosis.

Allan Friedman
NC, USA

There is an extensive literature demonstrating that repairing both the suprascapular and axillary nerves to restore function to the supraspinatus and deltoid muscles respectively, the major abductors of the arm at the shoulder, results in improved function as opposed to one or the other. This article confirms this observation in the setting of patients with brachial plexus nerve root avulsion injuries involving either the C5 and C6 levels or the C5, C6, and C7 levels using nerve transfers. In one group of 10 patients (single transfer), only the suprascapular nerve was repaired by directly transferring the distal spinal accessory nerve. In the other group of 10 patients (double transfer) in addition the anterior branch of the axillary nerve was repaired using a direct transfer of the radial branch to the long of the triceps muscle in cases of C5 and C6 avulsions or two intercostal nerves in the setting of C5-7 avulsions. The results comparing these two groups when motor strength was assessed by the MRC grading scale did show an advantage for the double transfer group that was not statistically significant. Better range of arm abduction when measured in degrees was seen with the double transfer compared to the single transfer procedure that was statistically significant when assessed using the evaluation criteria of the shoulder joint proposed by Samardzic et al. Although other studies have shown a similar result and this is a retrospective study with relatively small numbers, it nonetheless provides useful confirmatory information on patients operated on by a single group.

Michel Kliot
CA, USA