Int J Clin Exp Med 2016;9(11):22880-22885
www.ijcem.com /ISSN:1940-5901/IJCEM0032455

Original Article

Selective neurotization of the radial nerve in the axilla using intercostal nerve to treat complete brachial plexus palsy

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Received May 19, 2016; Accepted September 29, 2016; Epub November 15, 2016; Published November 30, 2016

Abstract: Background: Current nerve transfer for the restoration of wrist and finger extension of complete brachial plexus injuries (TBPI) result in poor outcomes. To overcome the mismatch in nerve size in intercostal nerve transfer to the radial nerve, a selective neurotization procedure was designed. Objective: To investigate the long-term results of selective neorotization of the radial nerve in the axilla using intercostal nerve to restore wrist and finger extension after TBPI. Methods: Intercosral nerve were transferred to and selective coapted with the medial portion of radial nerve in 31 patients with TBPI. Seven patients were <18 years old (adolescent group), and remaining 24 patients ≥18 years old (adult group). 14 patients were restored with 2 ICN (2 ICN group); the remaining 17 patients were reconstructed with three or more ICN (3 ICN group). Results: Postoperative mean follow-up period was 42.3 months (range, 26-81 months). In terms of finger and wrist extension recovery, there is no significant difference between the adult group and adolescent group. The motor power of finger, wrist extension reached M3 or greater 75%, 81.3% of patients underwent operation less than six months after injury, while 13%, 40% in patients treated in more six months. The difference between two groups was statistically significant. The motor function attained M3 or greater in 61.3% of patients for wrist extension and in 45.2% of patients for finger extension. The percentage of patients who regained M3 or greater muscle power of finger extension in 2 ICN group and 3 ICN group was 21.4% and 64.7%, respectively. There is significant difference between two groups. Conclusion: The surgical procedure is safe and lower mismatch between donor motor nerve and recipient nerve, can lead to effective functional recovery of wrist and finger extension.

Keywords: Brachial plexus, nerve transfer, wrist and finger extension, radial nerve

Introduction

Traumatic brachial plexus injuries (TBPI) are devastating events, which frequently occur in young adults and are mostly caused by high-energy force such as traffic accidents [1]. Multiple nerve transfers are the main methods for treating BPI [2, 3]. The primary goal in regaining upper-extremity function in adult patients is the restoration of elbow flexion [4, 5] and satisfactory results have been achieved. According to our knowledge, the intercostal nerves [6-10] and the contralateral C7 nerve root [11, 12] have been commonly used to restore wrist and finger extension function. However, wrist and finger extension did not recover as well as the flexion through nerve transfer. The reason of poor result is that none of the available motor donor nerves, including the phrenic nerve, the intercostal nerves, and motor branches of the cervical plexus, has a sufficient number of nerve fibers to match the radial nerve, and a long distance between the injury site and the extensor muscles [13]. If a thin donor nerve is coapted randomly to a radial nerve, the regenerating nerve fibers may grow into undesired muscle branches or cutaneous branches instead of the desired target extensor muscles. Therefore, it is hard to restore good function of finger and wrist extensor muscle by applying thin nerve to coapted with radial nerve. Recently Yang [14] reported good outcome of selective neurotization of the radial nerve in the axilla using a full-Length phrenic nerve to treat complete brachial plexus palsy. However, the phrenic nerve have been transferred to Mu-

Figure 1. The incision for inter coastal nerve transfer to the medial portion of radial nerve.

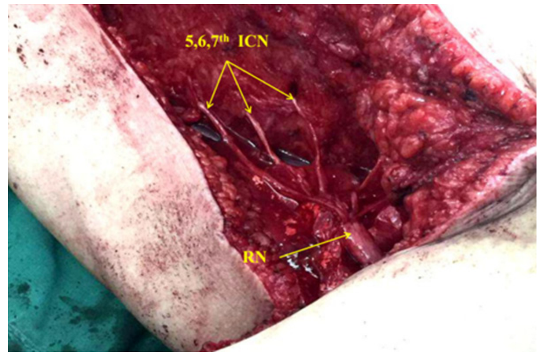

Figure 2. Three intercostal nerves were coapted to the medial portion of radial nerve end to end using 8/0 nylon.

sculocutaneous nerve to restore elbow flexion, which is considered more important for regaining upper-extremity function. Based on the previous anatomic study of yang, we selectively transfer intercostal nerve to radial nerve in the axilla. The surgical procedure and outcome are presented here.

Patients and methods

We carried out a retrospective review of 31 patients treated with selective transfer of ICN with radial nerve for finger and wrist extension after posttraumatic global BPI at the Department of Hand Surgery, Huashan Hospital. The inclusion criteria included global brachial plexus root avulsion, a minimum time of postoperative interval of >3 years, and selective ICN transfer to restore wrist finger extension from 2007 to 2012. The exclusion criteria included diabetes, Volkmann contracture, fracture on the affected limb, rib fracture on the affected side, and brain trauma.

All of the patients were confirmed to have global root avulsion by physical examination, preoperative and intraoperative electromyography (EMG), and intraoperative exploration. The patients were placed in the supine position with the head turned towards the healthy side, and a supraclavicular and subclavian incision was used for exploration (**Figure 1**). The brachial plexus was exposed and there was no nerve root in the intervertebral foramen.

Reconstruction methods

A longitudinal incision along the midaxillary line was made (**Figure 1**), and the incision became a Z shape in the axilla. The ICNs of the third to sixth ribs were identified and dissected along their course. The ICNs were passed through the serratus anterior muscle to the axilla.

A longitudinal medial arm incision was made to explorateantebrachial part of the radial nerve at the level of latissimusdorsi insertion in the axilla. Then it was cut off close to the lateral bundle and medial portion of radial nerve was identified. Two or three ICNs were coaptated to the medial portion of radial nerve end to end using 8/0 nylon (**Figure 2**). After the operation, a chest girdle was used to avoid tension of the nerve coaptation.

Postoperative rehabilitation

Physical therapy and electrostimulation therapy were started 4 weeks postoperatively. Patients were instructed to notice the recovery of wrist and digital extension when they were taking deep breaths. Electrodes were placed on the lateral thoracic wall and extensor carpi radialis muscle, ulnar extensor carpi muscle, extensor digitorum muscle for ICN transfer. Electrostimulation therapy could promote the growth of nerve axons by electric current.

Evaluation

The Medical Research Council muscle grading system was used for motor function evaluation. The muscle strength of the finger extensors was tested with the wrist extended at 20° to 30°. A return of muscle power of M3 or better was regarded as effective. We used electromyography (EMG) to evaluate the condition of nerve regeneration, which included a simple or a mixed phase, and newborn potential with lit-

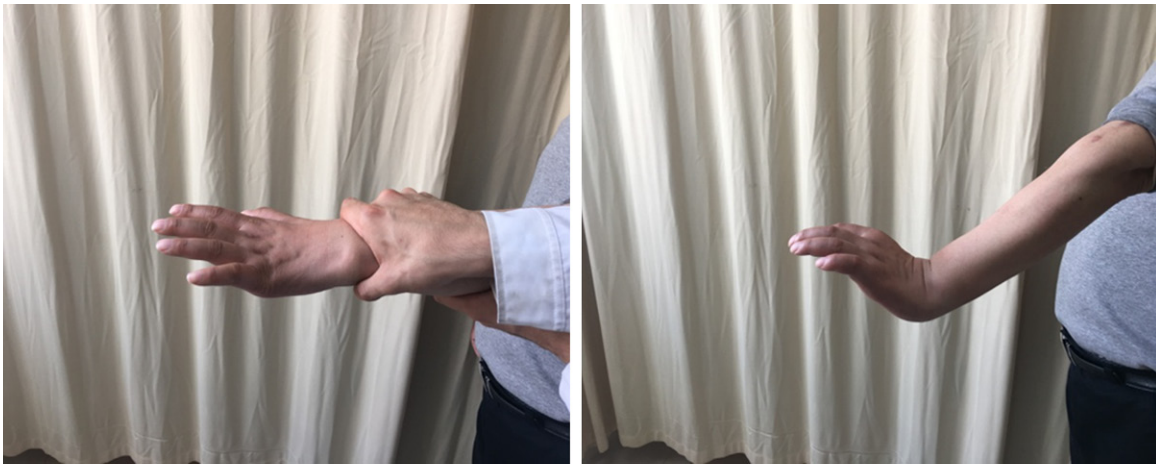

Figure 3. A 35 years old patient sustained a left total brachial plexus injury. The patient underwent surgical exploration and nerve transfer four months after the injury. 5, 6, 7th intercostal nerve transferred to medial portion of the radial nerve in the axilla. In addition, CC7 nerve root was transferred to lower trunk, phrenic nerve was transferred to musculocutanous nerve. The distal accessory nerve was used to neurotize the superascapular nerve for shoulder abduction. The 3, 4th intercostal nerve was transferred to triceps branch of radial nerve.

Table 1. Comparison of Finger and Wrist Extension Recovery Between the Adult Group and the Adolescent Group After Intercostal Nerve to Median Portion of Radial Nerve Transfer in the Level of Axilla

	n	Finger Extension, n (%)		Wrist Extension, n (%)	
		M4, M3	M2-0	M4, M3	M2-0
Adult group	24	2 (8.3), 7 (29.2)	15 (62.5)	5 (20.8), 9 (37.5)	10 (41.7)
Adolescent group	7	1 (14.2), 3 (42.9)	3 (42.9)	3 (42.9), 2 (28.55)	2 (28.55)
Fisher χ^2 (p)		2.94 (0.413)		2.71 (0.676)	

tle motor unit (MU) and no MU on the EMG screen. Normal muscle contraction could be recorded as a simple or a mixed phase, while newborn potential with little MU or no MU implied poor recovery.

Statistical analysis

Statistical analysis was performed with SPSS16.0 statistics software. The Fisher exact test was used to compare motor power recovery of the wrist and finger extension in adult group and adolescent group, in underwent operation within 6-month group and after 6-month group, patients who restored by two ICN or by three more ICNs.

Result

In this series, 31 patients underwent ICN transfer to the medial portion of radial nerve in the axilla level. Among the 31 patients 28 were male except three for females with mean age of 30.5 years (range 15-49) at the time of injury. The mean follow-up period was 42.3 months (range: 26-81 months). The delay in surgery ranged from 2 months to 13 months. 14 patients were restored with two ICN while 17 patients were restored with three or more ICN. Motor vehicle and motorcycle accidents accounted for injuries in 26 patients. Five patients suffered weight dropping on the shoulder and one dropped from a height.

MRC grading of wrist and finger extension

At the last follow-up, the motor power of wrist extension attained M4 in 9 patients, M3 in 10 patients, and M2-0 in 12 patients (**Figure 3**). Meaningful recovery (M3 or greater) of wrist extension was achieved in 61.3% (19 of 31) of patients. The muscle strength for finger extension reached M4 in 3 cases, M3 in 11 cases, and M2-0 in 17 cases. Meaningful finger extension restoration was seen in 45.2% (14 of 31) of patients.

Among the 31 patients, 7 patients were <18 years old (adolescent group), 24 patients age were >18 years old (adult group). The effective recovery results of finger extension were 57.1%

Table 2. Comparison of Finger and Wrist Extension Recovery Between the Time Operation Less than 6 Months Group and More than 6 Months Group After Intercostal Nerve to Median Portion of Radial Nerve Transfer in the Level of Axilla

	n	Finger Extension, n (%)		Wrist Extension, n (%)	
		M4, M3	M2-0	M4, M3	M2-0
Delay of operation <6 months	16	3 (18.8), 9 (56.2)	4 (25)	4 (25), 9 (56.3)	3 (18.7)
Delay of operation ≥6 months	15	0 (0), 2 (13.3)	13 (86.7)	3 (20), 3 (20)	9 (60)
Fisher χ^2 (p)		6.77 (0.01)		6.77 (0.01)	

Table 3. Comparison of Finger and Wrist Extension Recovery Between 2 ICN Group and 3 ICN Group After Intercostal Nerve to Median Portion of Radial Nerve Transfer in the Level of Axilla

	n	Finger Extension, n (%)		Wrist Extension, n (%)	
		M4, M3	M2-0	M4, M3	M2-0
2 ICN Group	14	0 (0), 3 (21.4)	11 (78.6)	1 (7.1), 5 (35.7)	8 (57.2)
3 ICN Group	17	3 (17.6), 8 (47.1)	6 (35.3)	8 (47.1), 5 (29.4)	4 (23.5)
Fisher χ^2 (p)		6.32 (0.029)		5.42 (0.075)	

in adolescent group and 37.5% for adult group. The difference between 2 groups in finger extension recovery was not significant (χ^2=2.94, P=0.413). The effective recovery results of wrist extension were 71.4% in adolescent group and 54.2% for adult group. The difference between 2 groups in wrist extension recovery was not significant (χ^2=2.71, P=0.676) (**Table 1**).

16 patients underwent operation less than six months of after injury, 15 patients treated in more than six months after injury (**Table 2**). The motor power of finger extension reached M3 or greater 75% and 13% in two groups respectively. The difference between 2 groups in finger extension recovery was statistically significant (χ^2=5.81, P=0.029). The motor power of wrist extension reached M3 or greater 81.3% and 40% in two groups respectively. The difference between 2 groups in wrist extension recovery was statistically significant (χ^2=6.77, P=0.01).

14 patients were restored with 2 ICN (2 ICN group); the remaining 17 patients were reconstructed with three or more ICN (3 ICN group). The motor power of finger extension reached M3 or greater in 21.4% (3 of 14) of patients in the 2 ICN group and in 64.7% (11 of 17) of patients in the 3 ICN group (**Table 3**). The difference between the 2 groups in terms of finger extension recovery was statistically significant (χ^2=6.32; P=0.029). The motor power of wrist extension reached M3 or greater in 42.9% (6 of 14) of patients in the 2 ICN group and in 76.5% (13 of 17) in the 3 ICN group. There was no significant difference between the 2 groups (χ^2=5.42; P=0.075).

Discussion

Nerve transfer is the traditional method for treatment of brachial plexus injury, some common reconstruction method gradually standardized. Shoulder and elbow function can be partially restored in patients with complete brachial plexus avulsion [12, 15, 16]. The majority of reports show poor results of the wrist and finger extension function in patients with brachial plexus avulsion [7, 8]. Because of the limited motor donor nerves, mismatches between donor motor nerve fibers and recipient sensory nerve fibers, and the long distance between the donor nerves and the target extensor muscles, the satisfactory finger and wrist extension cannot be reconstructed with the traditional methods of nerve transfer. For all we know, the donor nerves used to restore the radial nerve include the phrenic nerve, the contralateral C7 nerve root and intercostal nerves. In recent years, supraclavicular phrenic nerve transfer to Posterior Division of the Lower Trunk and the full length phrenic nerve transfer to radial nerve have been used in clinical, but the supraclavicular phrenic nerve usually used to restore the function of elbow flexion. Full length phrenic nerve transfer increase the risk of surgery, requirements of equipment and anesthesia that is hard to widely accepted. Although only CC7 matches the diameter of the radial nerve, however, CC7 is usually used to restore the function of finger flexion, which is considered a higher priority than finger extension. CC7 nerve root requires more time to reinnervate the target muscles compared with other donor nerves because of the long regenerating distance, moreover CC7 nerve root contains many sensory fibers, which will result in a high probability of mismatch. Anatomical and clinical study of full length phrenic nerve transfer to medial portion of radial nerve in axilla level demonstrate the possibility of Selective neurotization of the deep branch of radial nerve at the level of latissimusdorsi insertion in the axilla with thin nerve, and increase the possibility of donor motor nerve grow into the desired target extensor muscles. In our study we use intercostal nerve as donor nerve for this technicque instead of phrenic nerve.

In our study 31 patients with total brachial plexus avulsion were underwent treatment of intercostal nerve transfer to medial portion of radial nerve in the axillary level. The effective recovery of wrist and finger extension function was achieved 61.3% and 45.2% respectively. The result of recovery of finger extension function similar with result of phrenic nerve transfer to posterior division of the lower trunk to restore finger and elbow extension function in patients with total brachial plexus injuries (meaningful recovery of finger extension was 48%) [17]. The motor branch of one intercostal nerve has only 400 to 1300 nerve axons,the phrenic nerve has 1700 to 2700 axons [18], but motor branch axons of 2~3 intercostal nerve similar with phrenic nerve. The possibility of the occurrence of a mismatch in selective neurotization of the deep branch of radial nerve may lower than procedure of direct coaptation of radial nerve with phrenic nerve or multiple intercostal nerves. This might be the possible reason that contribute to similar result of two techniques.

Gu [19] proposed that use at least two intercostal nerve as donor nerve in intercostal nerve transfer surgery, previous study reports of difference in the results between the one intercostal nerve transfer and two intercostal nerve transfer [20]. In this series, there is significant difference in the result of finger extension function between 2 ICN and 3 ICN transfer group. This suggests that at least three intercostal nerves will get a better result for the restoration of the multiple different functioning target muscle.

The time between the moment of the injury and the surgical treatment is one of the factors that is more important in functional recovery [21]. In our study, there was a significant difference of successful wrist and finger extension recovery ($P<0.05$) between the delay of surgery within and without 6 months (**Table 3**). Narakas and Hentz [21] reported that the reconstruction was carried out before the fourth month and the recovery was more satisfactory. They suggest that early surgical intervention will result in better functional outcome. Our result is consistent with previous other's notion.

In our study, although the results of finger and wrist extension in adolescence group were better than adult group, the statistical analysis showed that the difference was not significant. This may be due to the unequal number of cases in each group [22]. In the adult group, the percentage of meaningful recovery of wrist extension and finger extension was 58.3% and 37.5%, respectively. It is worth noting that the extension of the fingers recovered better than expected results. It is worth noting that the result of finger extension recovery was greater than expected. Procedure of intercostal nerve transfer to the radial nerve is reports poor results of finger extension recovery, even in high-level radial nerve injury that causes paralysis of elbow, wrist, and digit extension, in the study of pan CH, When the radial nerve was repaired by using nerve graft, only 31% of patients achieved M3 or greater wrist and finger extension function [23]. Thus, the surgical technique of selective neurotization of the radial nerve with intercostals nerve is optimal method for patients with total brachial root avulsion, when the circumstance of the phrenic nerve as donor nerve for reconstruction of elbow flexion injured, CC7 as donor nerve for reconstruction of median nerve or flexor tendon transfers or distal nerve transfers are not feasible.

Conclusion

Selective neurotization of the radial nerve in the Axilla Using intercostal Nerve can simultaneously restore wrist and finger extension in patients with total brachial plexus avulsion. The surgical procedure is safe and lower mismatch between donor motor nerve and recipient nerve, can lead to effective functional recovery of wrist and finger extension.

Acknowledgements

This study was supported by the Department of Hand Surgery at the Huashan Hospital and the

Hand Function Research Center in Fudan University.

Disclosure of conflict of interest

None.

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