MUSCULOSKELETAL SURGERY
https://doi.org/10.1007/s12306-020-00653-z

ORIGINAL ARTICLE

Intercostal or ulnar nerve: Which donor nerve is to be used for reanimation of elbow flexion?

M. Emamhadi[1] · H. Behzadnia[2] · M. Zamanidoust[2] · I. Baghi[3] · R. Ebrahimian[4] · R. Emamhadi[5] · S. Andalib[6,7,8,9,10,11,12]

Received: 17 August 2019 / Accepted: 25 February 2020

Abstract

Background In total brachial plexus injury, intercostal nerves (ICNs) are used as donor nerves to restore the elbow flexion; albeit in upper brachial plexus injury (BPI), ulnar nerve provides a source of motor axons for this purpose. The present study set out to compare the restoration of elbow flexion by using these two donor nerves.

Methods Between 2010 and 2013, 24 adult patients with upper-middle BPI and 15 patients with total BPI undergoing elbow flexion restoration surgery were studied. Motor fascicle of flexor carpi ulnaris branch of ulnar nerve (mFCU nerve) procedure was utilized in upper-middle BPI, as well as transfer of ICN to biceps branch of the musculocutaneous nerve (MCN) in total BPI. Both techniques included sectioning, rerouting, and direct suturing of the biceps branch of the MCN. Follow-up consisted serial clinical examinations and EMG–NCV tests. Motor strength was recorded according to the British Medical Research Council grading system in that the results were reported as nonfunctional (grades M0–M2) and functional (grades M3–M5).

Result No significant difference was documented between the Oberlin procedure and ICN–MCN transfer in terms of reinnervation results ($P=0.6$). However, a significant difference in restoration of muscle force was found between the mFCU (95.83%) and ICN–MCN transfers (66.66%) ($P=0.02$).

Conclusion The evidence from the present study indicates that although ICN–MCN transfer is a viable method for reanimation of elbow flexion in BPI, mFCU nerve is a better donor if exists.

Keywords Brachial plexus injury · Ulnar nerve · Intercostal nerve · Nerve transfer

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s12306-020-00653-z) contains supplementary material, which is available to authorized users.

✉ S. Andalib
andalib@gums.ac.ir

1 Brachial Plexus and Peripheral Nerve Injury Center, Guilan University of Medical Sciences, Rasht, Iran

2 Department of Neurosurgery, Poursina Hospital, School of Medicine, Guilan University of Medical Sciences, Rasht, Iran

3 Guilan Road Trauma Research Center, Department of Surgery, Poursina Hospital, School of Medicine, Guilan University of Medical Sciences, Rasht, Iran

4 Department of Surgery, Poursina Hospital, School of Medicine, Guilan University of Medical Sciences, Rasht, Iran

5 Department of Biotechnology, School of Basic Sciences, Tonekabon Branch, Islamic Azad University, Tonekabon, Iran

6 Neuroscience Research Center, Department of Neurosurgery, Poursina Hospital, School of Medicine, Guilan University of Medical Sciences, Rasht, Iran

7 Guilan Road Trauma Research Center, Department of Neurosurgery, Poursina Hospital, School of Medicine, Guilan University of Medical Sciences, Rasht, Iran

8 Department of Nuclear Medicine, Odense University Hospital, Odense, Denmark

9 Research Unit of Clinical Physiology and Nuclear Medicine, Department of Clinical Research, Faculty of Health Sciences, University of Southern Denmark, Odense, Denmark

10 BRIDGE-Brain Research-Inter-Disciplinary Guided Excellence, Department of Clinical Research, University of Southern Denmark, Odense, Denmark

11 Research Unit of Psychiatry, Department of Psychiatry, University of Southern Denmark, Odense, Denmark

12 Department of Neurology, School of Medicine, University of New Mexico, Albuquerque, NM, USA

Introduction

Brachial plexus is shaped by the anterior rami of the lower four cervical nerves and the first thoracic nerve [5]. Traumatic brachial plexus injuries (BPI) in adults are devastating and can give rise to severe disability [1, 11, 23]. Severe brachial plexus injuries, which usually result from motor vehicle accidents, can lead to arm palsy with motor and sensory loss [6]. Restoration of motor recovery is carried out with priority of (1) elbow flexion, (2) shoulder abduction, (3) elbow extension, (4) finger flexion, and (5) protective sensory recovery on the fingers [7]. The restoration of elbow flexion using nerve transfer can be offered by reinnervation of the biceps muscle. Elbow flexion recovery using nerve transfer has been focused on reinnervation of the biceps muscle used for forearm supination and elbow flexion. In 1994, Oberlin first reported a direct transfer of a redundant flexor carpi ulnaris fascicle from the functioning ulnar nerve to the biceps branch of the musculocutaneous nerve (MCN) in order for restoration of elbow flexion [16]. In this procedure, rapid restoration of biceps function can be achieved by virtue of short distance between donor nerve and target biceps muscle. In order to reconstruct the elbow flexion, intercostal nerve (ICN) to MCN transfer is another option. Seddon first transferred ICN to MCN along with sural nerve interposition for reconstruction of elbow flexion in patients with BPI [20]. This transfer has also been used in all types of BPI, including total BPI with excellent outcomes for elbow flexion [22]. In this study, we compared the results of restoration of elbow flexion after transfer of ulnar nerve and ICN as donor nerves.

Materials and methods

Patient population

We retrospectively reviewed 24 adult patients with an upper BPI and 15 with total BPI undergoing surgery for restoring elbow flexion from 2010 to 2013. All the surgeries were performed by a single peripheral nerve surgeon. A motor fascicle of flexor carpi ulnaris branch of ulnar nerve (mFCU nerve) procedure was utilized in upper BPI and transfer of ICN to biceps branch of the MCN in total BPI.

Motor vehicle accidents and falling down were the cause of injuries. All the patients underwent serial clinical examinations, electrodiagnostic studies, and cervical MRI preoperatively.

Follow-up consisted postoperative serial clinical examinations and two rounds of EMG–NCV on the 6- and 12-month follow-ups. Motor strength was recorded by using the British Medical Research Council (MRC) grading system in that the results were reported as nonfunctional (grades M0, M1, and M2) and functional (grades M3, M4, and M5) [12]. Existence of the reinnervation evidence by using electromyography–nerve conduction velocity (EMG–NCV) test was also recorded.

Surgical technique

Musculocutaneous recipient nerve

In the anterioromedial aspect of the arm, a 10-cm incision was made. The MCN was explored between the biceps and brachialis muscles. The MCN was followed toward the distal end and the motor branch of the biceps was found. The motor branch of the biceps was released and cut as proximal as possible to have sufficient length of the nerve.

Ulnar nerve exposure

Ulnar nerve was exposed via the above-mentioned similar incision. The epineurium was opened under microscope and a fascicle predominantly innervating flexor carpi ulnaris muscle was confirmed by electrical stimulation and was selected. The selected ulnar fascicle was thereafter coapted to the biceps branch with 9-0 nylon suture under magnification.

Intercostal nerve harvesting

A thoracostomy incision was made at T4 exposing 3rd–6th ICNs. Subperiosteal dissection of the rib was done exposing the motor portion of the ICN and was then confirmed using a nerve stimulator. According to availability of the nerves, two or three ICNs were incised in an area where was closest to the sternum to have sufficient length required for direct anastomosis with the biceps branch of the MCN without use of an interposition graft. Under microscopic, the neurorrhaphy was performed without tension using a 10-0 nylon suture.

The limb was immobilized in an arm splint with the elbow at 90° flexion after the surgery to restrict movement of the shoulder and elbow joint for 4 weeks. Physiotherapy was commenced for active and passive range of motion along with motor reeducation after 1 month. There was no clinical evidence of donor nerve dysfunction.

Results

The present study investigated 39 patients undergoing nerve transfer surgeries for the elbow flexion restoration. Fifteen and 24 patients underwent ICN–MCN and mFCU nerve transfers, respectively.

The mean follow-up duration was 23.73 months in the patients undergoing ICN–MCN transfer, compared to 13.3 months in the patients undergoing mFCU nerve transfer. In mFCU nerve transfer group, 21 were males and 3 were females. In the ICN–MCN transfer group, 11 were males and 4 were females.

The average age of patients undergoing ICN–MCN and mFCU nerve transfers were 31.3 ± 10.4 and 31.7 ± 11.1 years, respectively. No significant differences in age were observed between the two groups ($P = 0.9$; 95% CI = – 7.5–6.8). On the final evaluation, out of the 15 patients undergoing ICN-MCN transfer, one showed M0 muscle force, one with M1 muscle force, three with M2 muscle force, five with M3 muscle force, five with M4 muscle force and none of them reached M5 muscle force. Therefore, 10 out of the 15 patients with ICN–MCN transfer regained functional elbow flexion (66.6%) (Fig. 1). In the mFCU nerve transfer group, one patient experienced M0 muscle force, one patient showed M3, 16 patients regained M4, and six patients had M5. Thus, 23 out of the 24 patients (95.8%) regained functional motor recovery (Fig. 2).

All of the patients were assessed by EMG–NCV after 6 and 12 months. In these assessments, EMG–NCV tests showed that reinnervation occurred in 14 cases (93.3%)

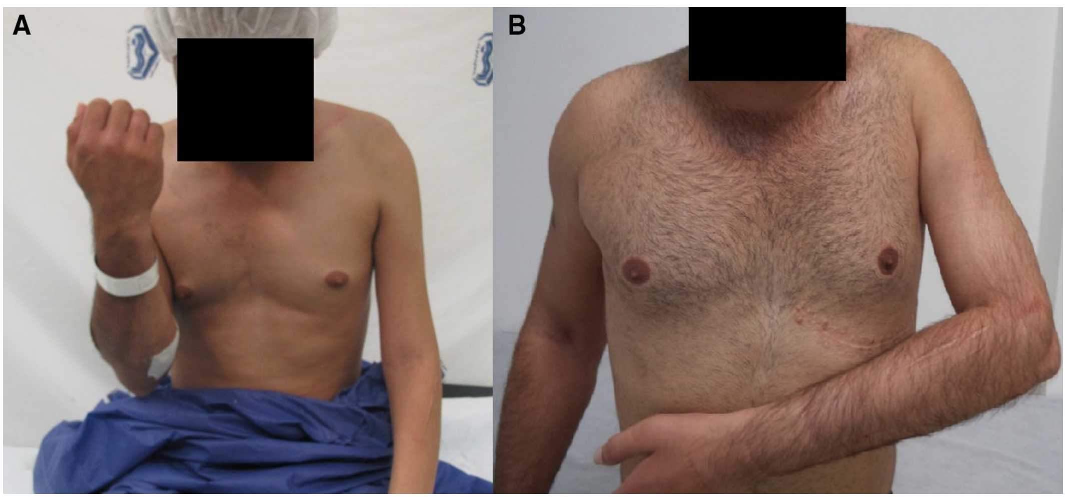

Fig. 1 Pre-op (**a**) and post-op (**b**)

Fig. 2 Pre-op (**a**) and post-op (**b**) clinical examination of a patient with upper brachial plexus injury undergoing mFCU nerve transfer

undergoing ICN–MCN transfer. Reinnervation was found in 23 cases (95.8%) with mFCU nerve transfer. However, no significant difference in reinnervation was seen between the mFCU nerve and ICN–MCN transfers ($P = 0.6$; 95% CI = 0.9–28.4).

A significant difference in biceps muscle force was found between the patients undergoing mFCU nerve (95.83%) and ICN–MCN (66.66%) transfers ($P = 0.02$; 95% CI = 1.1–111.5). Table 1 illustrates mechanism of injury and outcomes in the two nerve transfer groups.

Discussions

In the present study, we found that there was a more acceptable muscle force recovery by mFCU nerve transfer, compared to that in ICN–MCN transfer. The successful outcomes of mFCU procedure, compared to those in ICN transfer, are due to the close proximity of the stump of part of the ulnar nerve and the biceps branch of the MCN. In ICN transfer, the distance between the site of neurorrhaphy and target muscle is not comaprable with that in mFCU procedure, which offers a better recovery in the mFCU procedure. Moreover, there was no significant improvement in the reinnervation produced by the two nerve transfers. The two techniques were not found to produce significantly different reinnervation in our patients. However, reinnervation by itself is not a determining parameter of muscular strength, inasmuch as we found that it did not exert a considerable effect on elbow flexion recovery using the two surgical techniques.

Ulnar nerve (partial or FCU branch) transfer for restoration of elbow flexion is commonly used. We used mFCU nerve transfer in 24 patients of which 23 cases (95.83%) achieved functional recovery in elbow flexion. In addition, 6 cases (25%) recovered M5 muscle force. Teboul et al. [21] evaluated 32 patients with FCU of ulnar nerve to biceps branch of MCN (Oberlin procedure) and reported that 94% of the cases had ≥ M3 without significant donor morbidity.

In a study by Kakinoki et al. [9], 16 patients with BPI with partial ulnar nerve transfer in eight patients and ICN transfer in eight patients for restoration of elbow flexion function were studied. The necessary times to achieve M1 and M3 in elbow flexion were significantly shorter in the partial ulnar nerve transfer than in the ICN transfer ($P = 0.04$ for M1 and $P = 0.002$ for M3). Nevertheless, no significant difference was seen in the time obtaining full elbow flexion between the two groups. They reported no cases with M5 muscle force recovery. Kakinoki et al. [9] pointed out that their study weakness was a significant difference in the number of injured nerve roots between the nerve transfer groups. We used one mFCU nerve, while in a study conducted by Oberlin et al. [15], one or two motor fascicles of ulnar nerve were used, but the final results of the two studies were almost similar (95.8% vs. 97%).

Coulet et al. [3] performed partial ulnar nerve transfer and ICN transfer in 23 and 17 patients, respectively; and for both techniques, the transfer to the MCN was undertaken. Biceps reinnervation appeared earlier in the ulnar nerve technique than in the ICN ($P = 0.001$). Ten patients regained functional elbow flexion muscle force (> M3) in the ICN transfer group, compared with 20 patients in the ulnar nerve transfer group.

We demonstrated that results of elbow flexion function recovery in ICN–MCN transfer technique were 66.66%. Nagano et al. [13] achieved functional elbow flexion by using ICN–MCN transfer technique in 71% of their patients. The authors carried out the largest series to date on 156 patients and achieved a muscle strength of M3 and M4 in 66 and 45 patients, respectively.

Merrell et al. [10] achieved functional recovery in 72% of patients with ICN–MCN transfer without interposition graft. The authors also showed that ICN–MCN transfer with interposition graft had less effective results (47%). Narakas and Hentz [14] reported that 15 of 30 patients achieved a functional motor strength after ICN–MCN transfer. Wagner et al. [24] followed up 85 patients undergoing ICN–MCN transfer for an average time of 2.8 years and reported that 46 patients (54%) experienced functional elbow flexion (≥ M3); even so, 69 patients showed reinnervation on EMG at last follow-up.

We used three ICNs (3–5th or 4–6th ICN) in our surgical procedure with 66.66% success rate. Xiao et al. [25] argued that the nerve transfer was not influenced by the difference in the number of ICNs. And, two ICN transfers were mentioned to be sufficient for ICN–MCN transfer.

Chuang et al. [2] evaluated 66 cases undergoing in ICN–MCN and reported that 44 cases (67%) experienced ≥ M4. The authors recommended three ICNs due to a high number of axons and a more precise matching of MCN.

Our findings indicated that mFCU procedure had significant favorable results in elbow flexion function recovery, compared

Table 1 Mechanism of injury and outcomes in the two nerve transfer groups

Type of nerve transfer	Mechanism		Functional muscle force (≥ M3)	Evidence of reinnervation
	Falling down	Motor vehicle accident		
mFCU	2 (8.4%)	22 (91.6%)	23 (95.83%)	23/24
ICN-MCN	1 (6.7%)	14 (93.3%)	10 (66.66%)	14/15

with ICN–MCN; however, this was not in agreement with the results of the study of Kakinoki et al. [9]. In addition, the performance following Oberlin procedure was more optimal than the other techniques [15]. And, transferring fascicles from ulnar nerve was able to produce the best recovery of elbow flexion [8, 15, 19].

ICN consists mixed motor and sensory neuron; nevertheless, in mFCU procedure, the motor fascicles of ulnar nerve are used. Inasmuch as donor fascicles of ulnar nerve have more motor axons than the motor branch (main trunk) of the ICN, mFCU procedure shows a more favorable flexion strength in biceps muscle. The advantage of mFCU procedure over ICN transfer is the close proximity of the stump of part of the ulnar nerve and the biceps branch of the MCN. The distance between the site of neurorrhaphy and target muscle in ICN transfer is longer than in mFCU procedure, which causes a faster recovery in the latter. Central nervous system control is also a crucial parameter [17]. The role of plasticity in achieving excellent results in distal nerve transfers has been confirmed [4]. Reinnervation must occur within 1 year to restore even fifty percent of muscle function. The distance from neurorrhaphy site to motor end plate of the biceps is normally about ten centimeters [18].

Conclusion

The mFCU technique offers reliable donor motor axons for transfer in BPI and reinnervates the biceps properly. However, reinnervation does not guarantee muscle strength. MFCU procedure, as compared to ICN transfer, is more likely to improve elbow flexion function.

Acknowledgements The research was financially supported by Guilan University of Medical Sciences.

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 (Guilan University of Medical Sciences) and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent For this type of study, formal consent is not required.

References

1. Bhardwaj P, Bhardwaj N (2009) Motor grading of elbow flexion—is Medical Research Council grading good enough? J Brachial Plex Peripher Nerve Injury 4:3
2. Chuang DC, Yeh MC, Wei FC (1992) Intercostal nerve transfer of the musculocutaneous nerve in avulsed brachial plexus injuries: evaluation of 66 patients. J Hand Surgery 17:822–828
3. Coulet B, Boretto JG, Lazerges C, Chammas M (2010) A comparison of intercostal and partial ulnar nerve transfers in restoring elbow flexion following upper brachial plexus injury (C5 – C6 ± C7). J Hand Surg 35:1297–1303
4. de Sousa AC, Guedes-Correa JF (2016) Post-Oberlin procedure cortical neuroplasticity in traumatic injury of the upper brachial plexus. Radiol Bras 49:201–202
5. Emamhadi M, Alijani B, Andalib S (2016) Long-term clinical outcomes of spinal accessory nerve transfer to the suprascapular nerve in patients with brachial plexus palsy. Acta Neurochir 158:1801–1806
6. Emamhadi M, Andalib S (2018) The first experience of triple nerve transfer in proximal radial nerve palsy. World Neurosurg 109:351–355. https://doi.org/10.1016/j.wneu.2017.10.033
7. Flores LP (2011) Brachial plexus surgery: the role of the surgical technique for improvement of the functional outcome. Arq Neuropsiquiatr 69:660–665
8. Frey M (2000) Avulsion injuries to the brachial plexus and the value of motor reinnervation by ipsilateral nerve transfer. SAGE Publications, London
9. Kakinoki R, Ikeguchi R, Dunkan SF, Nakayama K, Matsumoto T, Ohta S, Nakamura T (2010) Comparison between partial ulnar and intercostal nerve transfers for reconstructing elbow flexion in patients with upper brachial plexus injuries. J Brachial Plex Peripher Nerve Injury 5:4
10. Merrell GA, Barrie KA, Katz DL, Wolfe SW (2001) Results of nerve transfer techniques for restoration of shoulder and elbow function in the context of a meta-analysis of the English literature. J Hand Surg 26:303–314
11. Moran SL, Steinmann SP, Shin AY (2005) Adult brachial plexus injuries: mechanism, patterns of injury, and physical diagnosis. Hand Clin 21:13–24
12. Nagano A, Ochiai N, Okinaga S (1992) Restoration of elbow flexion in root lesions of brachial plexus injuries. J Hand Surg 17:815–821
13. Nagano A, Yamamoto S, Mikami Y (1995) Intercostal nerve transfer to restore upper extremity functions after brachial plexus injury. Ann Acad Med Singap 24:42–45
14. Narakas AO, Hentz VR (1988) Neurotization in brachial plexus injuries. Indication and results. Clin Orthop Relat Res 237:43–56
15. Oberlin C, Ameur NE, Teboul F, Beaulieu J-Y, Vacher C (2002) Restoration of elbow flexion in brachial plexus injury by transfer of ulnar nerve fascicles to the nerve to the biceps muscle. Tech Hand Upper Extrem Surg 6:86–90
16. Oberlin C, Beal D, Leechavengvongs S, Salon A, Dauge MC, Sarcy JJ (1994) Nerve transfer to biceps muscle using a part of ulnar nerve for C5–C6 avulsion of the brachial plexus: anatomical study and report of four cases. J Hand Surg 19:232–237
17. Pondaag W, Malessy MJA (2014) Intercostal and pectoral nerve transfers to re-innervate the biceps muscle in obstetric brachial plexus lesions. J Hand Surg (Eur Vol) 39:647–652
18. Ruch DS, Friedman A, Nunley JA (1995) The restoration of elbow flexion with intercostal nerve transfers. Clin Orthop Relat Res 314:95–103
19. Russell T (1999) Surgical disorders of the peripheral nerves. R. Birch, G. Bonney, CB Wynn Parry. 283 × 223 mm. Pp. 539. Illustrated. 1998. Edinburgh: Churchill Livingstone. Br J Surg 86:429
20. Seddon HJ (1963) Nerve grafting. J Bone Joint Surg Br 45:447–461
21. Teboul F, Kakkar R, Ameur N, Beaulieu J-Y, Oberlin C (2004) Transfer of fascicles from the ulnar nerve to the nerve to the biceps in the treatment of upper brachial plexus palsy. JBJS 86:1485–1490

22. Tsuyama NHT (1968) Reconstructive surgery for traumatic brachial plexus injuries. Clin Orthop 3:675–687
23. Tung TH, Mackinnon SE (2010) Nerve transfers: indications, techniques, and outcomes. J Hand Surg 35:332–341
24. Wagner E, Hundepool CA, Kircher M, Spinner R, Bishop A, Shin AY (2015) Intercostal nerve transfer to restore elbow flexion: level 4 evidence. J Hand Surg 40:e12
25. Xiao C, Lao J, Wang T, Zhao X, Liu J, Gu Y (2014) Intercostal nerve transfer to neurotize the musculocutaneous nerve after traumatic brachial plexus avulsion: a comparison of two, three, and four nerve transfers. J Reconstr Microsurg 30:297–304