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HANSUR-238; No. of Pages 6

ARTICLE IN PRESS

Hand Surgery and Rehabilitation xxx (2018) xxx–xxx

Available online at ScienceDirect www.sciencedirect.com

Elsevier Masson France EM|consulte www.em-consulte.com

Original article

Postoperative motor deficits following elbow flexion reanimation by nerve transfer☆

Déficits moteurs postopératoires après transfert nerveux de réanimation de la flexion du coude

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ARTICLE INFO

Article history:
Received 23 May 2018
Received in revised form 6 July 2018
Accepted 11 July 2018
Available online xxx

Keywords:
Anterior interosseous nerve
Brachial plexus
Elbow flexion
Nerve transfer
Oberlin's procedure
Postoperative deficit

ABSTRACT

We aimed to assess the rate and type of postoperative motor deficits that might be encountered following elbow flexion reanimation using ulnar- and/or median-based side-to-end nerve transfers in patients with brachial plexus injuries. All patients who underwent elbow flexion reanimation between November 2015 and October 2017 at our facility by nerve transfer based on partial harvests of the median and/or ulnar nerves were included. Postoperative clinical assessment was conducted the day after surgery to identify motor deficits in the territory of the harvested nerves. If a clinically noticeable deficit was present, the type and extent of the deficit were noted, and postoperative clinical evaluations were conducted monthly to determine its progression. After reviewing the charts of 27 consecutive patients, 4 patients were found to have a postoperative motor deficit (15%). In all four cases, the deficit was limited to the anterior interosseous nerve (AIN) territory in patients who underwent a double transfer (i.e., ulnar-to-biceps and median-to-brachialis). With clinical impairments of the flexor pollicis longus and/or the flexor digitorum profundus of the index and third fingers initially ranging from grade-0 to grade-3 strength, full recovery to preoperative strength levels occurred in all cases after a mean of 7 months' follow-up. Transient motor deficits may be observed in the AIN territory following elbow flexion reanimation when a median-to-brachialis nerve transfer is associated with the original Oberlin procedure.

Mots clés :
Nerf interosseux antérieur
Plexus brachial
Flexion du coude
Transfert nerveux
Technique d'Oberlin
Déficit postopératoire

RÉSUMÉ

Notre but était d'évaluer l'incidence, le type et l'évolution des déficits moteurs postopératoires dans les territoires des nerfs ulnaire et/ou médian pouvant être observés à la suite de transferts nerveux latéro-terminaux réalisés pour réanimer la flexion du coude. Tous les patients souffrant d'une paralysie de la flexion du coude ayant bénéficié de transferts nerveux partiels de nerf médian et/ou ulnaire dans notre service entre novembre 2015 et octobre 2017 furent inclus. Une évaluation clinique était réalisée le lendemain de l'intervention à la recherche de déficits moteurs dans les territoires des nerfs prélevés. En cas de déficit cliniquement identifiable, le type et l'étendue du déficit initial était notée, et un suivi mensuel était instauré afin d'en apprécier l'évolution. Les dossiers de 27 patients consécutifs furent analysés, dont ceux de 4 patients présentant un déficit moteur postopératoire (15 %). Dans ces quatre cas, il s'agissait d'un déficit limité au territoire du nerf interosseux antérieur (NIOA) chez des patients ayant bénéficié d'un double transfert (i.e., ulnaire-biceps brachialis et médian-brachialis). Avec une force

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https://doi.org/10.1016/j.hansur.2018.07.004
2468-1229/

Please cite this article in press as: Le Hanneur M, et al. Postoperative motor deficits following elbow flexion reanimation by nerve transfer. Hand Surg Rehab (2018), https://doi.org/10.1016/j.hansur.2018.07.004

postopératoire immédiate évaluée entre 0 et 3 sur 5 au niveau du flexor pollicis longus et/ou du flexor digitorum profundus des 2e et 3e doigts, tous les patients récupérèrent leur force préopératoire après un délai moyen de 7 mois. Lors de la réanimation de la flexion du coude par transfert nerveux, des déficits moteurs transitoires peuvent être observés dans le territoire du NIOA en cas de transfert médian-brachialis.

1. Introduction

There is currently a shift in brachial plexus injury (BPI) management in using surgery to address motor deficits [1]. Originally, grafting of nerves from intact cervical root stumps to primary functional targets were recommended in cases of post-ganglionic lesions, and palliative surgery was considered as the only viable option in cases of avulsion injuries [2]. However, since the initial description of a nerve transfer being performed to reanimate elbow flexion in 1994 [3], this alternative has become increasingly popular among the surgical community [4].

Depending on the type of harvest, nerve transfers may be divided in two categories: either a distal motor branch of a functioning muscle is harvested in its entirety (i.e., end-to-end transfer), or motor fascicles from a proximal composite nerve are selected with intraoperative neurostimulation (i.e., side-to-end transfer). They are sutured end-to-end to the affected target in both cases (i.e., end-to-end fascicular sutures) [5]. While postoperative deficits are inevitable in the territory of the selected branch in end-to-end transfers, most authors consider that the plexiform nature of proximal nerves seems to circumvent such shortcomings in side-to-end transfers [3,6,7].

For elbow flexion, Oberlin et al. described the first side-to-end transfer in upper BPI in which the ulnar nerve was partially harvested and transferred to the biceps brachii motor branch [3]. In 2006, they recommended performing an additional side-to-end transfer to improve the chances of recovery using motor fascicles from the median nerve to reinnervate the brachialis muscle [8]. Since then, numerous teams have reported highly satisfactory outcomes with both techniques [6–15]. However, very little information exists in the literature on postoperative deficits in the territories of the harvested nerves.

The objective of this study was to assess the rate and the type of postoperative motor deficits that may occur following elbow flexion reanimation using nerve transfer and to describe their evolution and management.

2. Patients and methods

2.1. Population

Between November 2015 and October 2017, all patients who underwent elbow flexion reanimation using nerve transfer based on the median and ulnar nerves were included. Preoperative physical examination focused on defining the type and extent of the palsy and determining the available therapeutic options; motor function assessment was conducted with the British Medical Research Council (BMRC) grading system [16]. An electrodiagnostic study was conducted preoperatively in all patients to rule out electrical reinnervation signs in the targeted muscles (i.e., biceps brachii and brachialis muscles).

2.2. Surgical technique and postoperative care

All patients were operated on by the last author (TL), using surgical techniques previously described in the literature [3,5,17,18]. Our strategy was primarily to reanimate both elbow flexors by performing ulnar-to-biceps and median-to-brachialis (UBMB) double nerve transfers. In cases of a positive response from one of the two elbow flexors to intraoperative neurostimulation, a single transfer was conducted toward the unresponsive muscle, ulnar-based, in order to increase the chances of elbow flexion recovery.

The patient was placed supine, with their upper limb draped free and abducted 90° from the torso. An incision was made on the medial aspect of the proximal half of the arm to open the humeral canal. The musculocutaneous nerve was identified proximally and dissected distally to separate the lateral antebrachial cutaneous nerve from the two motor branches—to the biceps muscle proximally and to the brachialis muscle distally. Once the perineurium was opened longitudinally with a No. 15 scalpel blade under microscope magnification, fascicular dissection was performed using microsurgical instruments, including non-toothed forceps and smooth-tip curved scissors. The fascicles were gradually separated from one another using the scissors while putting gentle axial traction on the fascicular epineurium with the forceps to preserve the vasa nervorum. Intraoperative neurostimulation (Vari-Stim®, Medtronic, Minneapolis, MN, USA) of each musculocutaneous motor branch was then used to confirm complete palsy of both muscles before any harvesting was carried out. The ulnar nerve was then identified and intraneural dissection was performed similarly at the level of the biceps brachii motor branch. Redundant fascicles to the flexor carpi ulnaris (FCU) were selected using electrical stimulation, whereas fascicles to the flexor digitorum profundus (FDP) and intrinsic muscles of the hand were preserved. The median nerve was then dissected to identify motor fascicles to the pronator teres (PT) and/or the palmaris longus (PL) at the level of the brachialis motor branch. If the response to intraoperative neurostimulation of the ulnar nerve fascicles was unsatisfactory (i.e., C5-C8 palsy), a second harvest from the median nerve was made proximally, at the level of biceps brachii motor branch (MBMB), while selecting fascicles to the flexor carpi radialis. Fascicular groups from the donor nerves were selected so their diameter was similar to the targeted musculocutaneous nerve branches. Harvested fascicles were then brought together flush with the motor branches to the biceps brachii and/or the brachialis muscles, sutured without tension with non-absorbable monofilament 9-0 nylon sutures (Ethilon, Ethicon, Sommerville, NJ, USA) and coated with fibrin-based bio-glue (Tisseel™, Baxter, Deerfield, IL, USA). Hemostasis was achieved using bipolar electrocautery prior to layer-by-layer subcuticular wound closure without a drain.

Postoperatively, the patient was placed in a resting sling for three weeks. Rehabilitation started when the sling was removed with elbow passive mobilization until active function was obtained. The day after surgery, a physical examination was performed by the operating surgeon to look for postoperative motor deficits in the territory of the harvested nerves. In cases of immediate clinical deficits, muscle strength was assessed monthly using the BMRC scale. The examinations were repeated monthly within the first year following the surgery to determine the time frame of clinical elbow flexion recovery.

Table 1
Cohort characteristics.

Patients	27
Age at surgery (years)	34 ± 16 (18; 80)
Sex (M/F)	22/5
Injury mechanism	
Motor vehicle accident	23
High energy fall	2
Sports injury	1
Glass wound	1
Initial presentation	
C5-C6 BPI	14
C5-C7 BPI	7
C5-C8 BPI	4
MCN palsy	2
Preoperative delay (months)	6 ± 3 (3; 14)
Type of nerve transfer	
UBMB	22
MBMB	3
UB	2
Follow-up (months)	18 ± 8 (7; 30)
Elbow flexion strength at last visit (%)	
BMRC grade 3	15
BMRC grade 4	81
BMRC grade 5	4

Results are presented as counts or mean ± standard deviation (range). M: male; F: female; BPI: brachial plexus injury; MCN: musculocutaneous nerve; UBMB: ulnar to biceps brachii and median to brachialis; MBMB: median to biceps brachii and brachialis; UB: ulnar to brachialis; BMRC: British Medical Research Council.

2.3. Data collection and statistical analysis

Investigations were conducted according to the 1964 Declaration of Helsinki ethical standards and to the MR-003 reference methodology [19]; this study was registered in the CNIL database register (No. 2126573 v 0) and each patient was individually informed and consented before any data collection.

Charts were reviewed to provide patient demographics and history, initial examination findings, nerve procedures performed, and follow-up data. In patients with postoperative deficits, the territory, the evolution and the management of the deficit were reported.

3. Results

3.1. Patient characteristics

Twenty-seven consecutive patients who underwent elbow flexion reanimation using nerve transfer based on partial harvests of the median and/or the ulnar nerves were included. The details of the cohort are given in Table 1. During follow-up, a motor deficit was identified in four patients (15%) who had undergone UBMB transfer (Table 2).

3.2. Postoperative deficits

The first postoperative deficit was observed in a 31-year-old woman (Patient 11–Supplemental Digital Content) who had been involved in a motor vehicle accident and suffered an anterior glenohumeral dislocation with a humeral neck fracture, with complete posttraumatic palsy of the left radial and musculocutaneous nerves. Open reduction and proximal intramedullary nailing were performed on an emergency basis by another team, without any surgical procedure to address the neurologic deficits. She was referred to our clinic 14 months after the accident with no sign of recovery; a UBMB double transfer was performed to reanimate elbow flexion. The day after surgery, she had a complete motor deficit of the FDP of the index finger (FDP2) and the flexor pollicis longus (FPL), with grade-0 strength observed in both muscles. She spontaneously started to recover some active motion 2 months after the surgery (i.e., grade-2 strength) in both muscles, and fully recovered after 15 months of follow-up. The radial palsy was addressed 4 months after the nerve surgery through palliative tendon transfers, including PT to extensor carpi radialis brevis and FCU to extensor digitorum communis and rerouted extensor pollici longus.

The second case was a 24-year-old man (Patient 13–Supplemental Digital Content) who was involved in a motor vehicle accident and had extensive proximal palsy of the left brachial plexus (i.e., C5-C7) on initial examination. UBMB transfer was performed 4 months after the accident, along with nerve grafts from the C5 root toward the suprascapular and the axillary nerves to reanimate shoulder function, while elbow extension was addressed by transferring three intercostal nerves to the long

Table 2
Postoperative motor deficits.

Case	Demographics			Surgery			Clinical progression					
	Sex	Age (years)	Type of injury	Preoperative delay (months)	Elbow flexion transfer	Associated nerve surgery	Postoperative deficit				Elbow flexion recovery	
							BMRC grade				BMRC grade at last follow-up	Recovery time (months)
							Location	After surgery	At last follow-up	Recovery time (months)		
1	F	31	MCN palsy	14	UBMB	–	FDP2; FPL	0	5	15	4	9
2	M	24	C5-C7 BPI	4	UBMB	C5 to AN + SSN ICN to LHTMB	FPL	3	5	3	4	7
3	M	64	C5-C6 BPI	10	UBMB	UN + LHTMB to AN	FDP2; FPL	3	5	7	4	8
4	M	24	C5-T1 BPI (partial recovery)	7	UBMB	C7 to SSN UN + LHTMB to AN	FDP2; FDP3; FPL	1 to 2	3	1	4	6

BMRC: British Medical Council Research; F: female; M: male; MCN: musculocutaneous nerve; C: cervical root; T: thoracic root; BPI: brachial plexus injury; UBMB: ulnar to biceps brachii and median to brachialis transfer; AN: axillary nerve; SSN: suprascapular nerve: ICN: intercostal nerves: LHTMB: long head of triceps brachii motor branch; UN: ulnar nerve; FDP: flexor digitorum profundus; FPL: flexor pollicis longus.

head of triceps brachii motor branch. The day after surgery, grade-3 strength was noted in the FPL. Full recovery was obtained after 3 months of follow-up.

A 64-year-old man with a right C5-C6 brachial plexus stretch injury (Patient 17–Supplemental Digital Content) was referred to our clinic 9 months after a motorcycle accident. Nerve surgery was performed 10 months after the trauma, with UBMB transfer for elbow flexion and double transfer toward the axillary nerve, including ulnar fascicles to the posterior branch (i.e., teres minor and posterior deltoid motor branches, after exclusion of the sensory branch, the upper lateral brachial cutaneous nerve) and the long head of the triceps brachii motor branch to its anterior branch; both transfers were performed through an axillary approach. No nerve surgery was performed toward the suprascapular nerve since a satisfactory response of both supraspinatus and infraspinatus muscles to electrical stimulation was found intraoperatively. Postoperatively, while no deficit was found in the ulnar nerve territory despite two harvests, the patient had a partial motor deficit (i.e., grade-3 strength) of the FPL and FDP2 muscles. After 7 months of follow-up, both muscles had fully recovered.

The last postoperative deficit was observed in a 24-year-old man (Patient 23–Supplemental Digital Content) who presented with a BPI secondary to a motor vehicle accident. Initially complete, the palsy recovered partially during the first 6 months following the accident. Preoperative examination (i.e., 7 months after the trauma) found a full recovery of elbow, wrist and finger extension and of the intrinsic muscles of the hand. Residual palsy affected shoulder function, elbow flexion, along with a partial motor deficit in the anterior interosseous nerve (AIN) territory, with grade-3 strength noted in the FPL, FDP2 and FDP3 muscles. UBMB double transfer was performed for elbow flexion, along with partial transfer of the ipsilateral C7 root (i.e., pectoralis major fascicles) to the suprascapular nerve and double transfer to the anterior and posterior branches of axillary nerve for shoulder function, as previously described. The day after surgery, the preoperative AIN deficit had increased, with grade-1 strength observed in the FPL and FDP2 muscles and grade-2 strength observed in the FDP3 muscle. One month after the surgery, the patient recovered grade-3 strength in all muscles, but did not make any further progress over time. After six months of follow-up, palliative tendon transfers (i.e., the FDP2 and FDP3 sutured at the forearm level to the FDP4 and FDP5, and the extensor carpi radialis longus transferred to the FPL) were refused by the patient who considered his function acceptable and did not want to undergo any further surgery.

4. Discussion

In this study, we reviewed the charts of 27 patients who underwent side-to-end nerve transfers based on the median and ulnar nerves to reanimate elbow flexion, focusing on motor deficits in the territory of donor nerves. Four cases of immediate postoperative deficit affecting the AIN were outlined, with complete spontaneous recovery to the preoperative status in all cases. Despite the transient nature of these deficits and the straightforward treatment solutions if they persist, we believe that such insight is of vital importance, especially in terms of preoperative patient information and subsequent postoperative management.

4.1. Surgical learning curve

When performing a nerve transfer, several intraoperative pearls and pitfalls can make the difference between a successful and a failed transfer [1]. During the nerve harvest, the surgeon has to take the correct amount of motor fascicles from the donor nerve, based on the diameter of the target nerve [2]. Furthermore, these fascicles have to be expandable, selecting redundant motor branches to the extent possible and avoiding the ones needed for crucial functions [18]. During the transfer, the suture has to be tensionless to avoid any dead space between neural edges and subsequent excessive scarring; careful microdissection is needed during the whole process, since excessive traction may cause neurapraxia or axonotmesis due to tensile and shear forces [20].

Given that this cohort featured the first two years of practice of the last author as a senior surgeon in a referral center for peripheral nerve surgery, one explanation for these complications might be the surgeon's learning curve, inherent to every surgical procedure [21]. Since the surgeon already had significant experience in microsurgery with several years of practice in hand surgery that included vascular and nerve trauma surgery, along with his increasing experience in peripheral neurosurgery during two years of practice with more than 200 nerve transfers performed within that time, one could expect the complication rate to decrease over time [22]. However, these four cases were spread over the whole inclusion period, with the last two occurring within the last 6 months. Moreover, with grade-3 or grade-4 elbow flexion strength observed in all patients after a mean period of 7 months, including those with postoperative deficits, all transfers appeared to be successful. One could then argue that it was not the transfer but the harvesting technique itself that was not fully mastered, accounting for either Sunderland type-2 lesions due to excessive fascicular traction during intraneural dissection, or improper selection of fascicles with intraoperative neurostimulation. While rather straightforward, the fact that these surgeon-related causes may be the only explanation for clinically noticeable deficits in the AIN appeared to be inconsequential to us.

4.2. Anatomic predisposition

In the anatomical portion of their original paper, Oberlin et al. observed that the motor branch issued from the musculocutaneous nerve to the biceps brachii entered the muscle at a mean distance of 12 cm from the acromion, whereas the motor branch to the brachialis entered the muscle at a mean distance of 17 cm from the acromion [3]. Subsequently, when performing UBMB transfer, the median nerve is harvested more distally than the ulnar nerve. Since the plexus formation between nerve fascicles decreases as they progress distally, the median nerve's partial transfer to the brachialis motor branch may resemble an end-to-end transfer rather than a side-to-end one [20]. Moreover, while the AIN arises from the median nerve approximately 3 cm distal to the intercondylar line, analysis of the intraneural anatomy of the median nerve at the elbow level showed that the AIN fascicles could be identified within the median nerve for a long distance proximal to its macroscopic separation [23]. Therefore, even if the surgeon properly selects fascicles to the PT or PL, any fascicular traction injuries that might occur during intraneural dissection may be more noticeable clinically during the postoperative follow-up since they would affect terminal branches with fewer interfascicular connections.

Furthermore, in four patients of our cohort, an additional ulnar-based harvest was performed to reinnervate the posterior branch of the axillary nerve through an axillary extension of the medial brachial approach [24]. FCU fascicles were also selected, in addition to those used in the ulnar-based transfer for elbow flexion; no postoperative deficits in the ulnar territory were observed in any of these patients. Additionally, in three patients with poor responses to intraoperative ulnar nerve stimulation (i.e., C5-C8 palsy), two fascicles were harvested from the median nerve, one proximal for the biceps brachii motor branch and one distal for the brachialis motor branch (MBMB). No deficit was observed in these subgroups of patients, supporting the assumption that the harvest level might be of greater significance than the number of transferred fascicles. We believe that the association of the distal location of the partial median nerve harvest with proximal AIN individualization might predispose patients to these specific deficits when combined with the surgeon-dependent factors that we previously described.

4.3. Therapeutic implications

In order to prevent such shortcomings, one option could be to modify the existing UBMB transfer by performing the median nerve harvest more proximally, at the level of the ulnar nerve harvest, which would provide more interfascicular plexus connections; based on the same principle, another option would be a secondary ulnar-based transfer. However, since reinnervation will be better when the suture is more proximal to the motor end-plates, functional outcomes may be impacted by such modifications [18].

Previous authors also questioned the very necessity of a double nerve transfer to reanimate elbow flexion [25]. In their triple nerve transfer designed to address cases of C5-C6 palsy, Bertelli and Ghizoni used only one of them to reanimate elbow flexion (i.e., ulnar-to-biceps) [10,26]. Similarly, satisfactory outcomes were reported by Leechavengvongs et al. with a single ulnar-based nerve transfer for elbow flexion reanimation, and Sungpet et al. with a single median-based nerve transfer [7,27,28]. In a retrospective study, Carlsen et al. compared the patients' postoperative results based on the type of surgery they had received for elbow flexion, whether it was a single (n = 23) or double (n = 32) transfer. No significant difference was found between the two groups in terms of elbow flexion and supination strength and functional outcomes [29]. A prospective randomized study of 40 patients by Martins et al. compared single (n = 20) and double (n = 20) transfers and confirmed these findings, with no significant difference between the two techniques in terms of functional outcomes. However, given that the authors had to limit their sample size to less than 25% of the number of patients outlined in their power analysis to complete their study (i.e., 40 patients analyzed in total instead of 84 in each group), the possibility of a statistical type II error due to the small sample size cannot be ruled out [15]. The morbidity of the two techniques was evaluated as well, including the postoperative alterations on handgrip and lateral pinch grip strengths. The authors reported 3 cases (15%) of impaired handgrip strength after a single transfer versus 5 cases (25%) in the double transfer group; similarly, worsening of lateral pinch grip was noted in 2 patients (10%) following a single transfer and in 7 patients (35%) following a double transfer. The authors reported that all postoperative deficits were transient, and they fully recovered spontaneously.

4.4. Limitations

The findings of our study should be considered in the light of its inherent limitations. As this is a retrospective case series, data was not collected prospectively. More precise and objective pre- and postoperative measurements of the deficits, such as grip or pinch strength were unavailable in some charts. Similarly, intraoperative data such as the precise location of the harvest based on anatomical landmarks (e.g., acromion process, medial epicondyle), might have been helpful to look for potential correlations between distal harvesting and postoperative deficits. Furthermore, since the chart review was based on data collected by the operating surgeon, an observation bias might exist. Finally, due to the short inclusion period and the small number patients requiring such surgery, the sample size was relatively small.

5. Conclusion

Clinically noticeable postoperative motor deficits following side-to-end nerve transfers to reanimate elbow flexion appear to be relatively common although they are transient with a full recovery of preoperative function. Observed solely in the AIN territory following a median-to-brachialis transfer, such deficits may be the result of a combination of anatomical predispositions of the median nerve, harvests performed in a relatively distal location and surgeon-related factors. While these findings should be disclosed during preoperative information of the patient, its therapeutic implications in terms of the optimal number of nerve transfers to perform for elbow flexion reanimation has yet to be determined.

Funding statement

The authors received no financial support for the research, authorship, and/or publication of this article.

Ethical standards

The data collection consisted in a retrospective review of a patient chart. Where the study was conducted (i.e., Paris, France), the Institutional Review Board does not examine retrospective studies, and subsequently does not issue formal advice on a letter. However, investigations were conducted according to the 1964 Declaration of Helsinki ethical standards and to the MR-003 reference methodology[1]; the protocol was registered in the registry of the National Commission for the Computer Science and Liberties (Commission Nationale de l'Informatique et des Libertés–CNIL) register (Declaration No. 2126573 v 0) and the patient and his legal guardians were informed and gave their consent before any data collection and analysis.

Disclosure of interest

The authors declare that they have no competing interest.

Appendix A. Supplementary data

Supplementary data (Supplemental Digital Content) associated with this article can be found, in the online version, at http://www.sciencedirect.com and https://doi.org/10.1016/j.hansur.2018.07.004.

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