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Original Investigation

Nerve Grafting versus Common Infraclavicular Intraplexal Nerve Transfer in Elbow Flexion Restoration

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ABSTRACT

AIM: To compare the results of nerve grafting versus common infraclavicular intraplexal nerve transfer in elbow flexion restoration.

MATERIAL and METHODS: The study included 39 patients with upper brachial plexus palsy who were operated using common intraplexal nerve transfer (Oberlin procedure) and the thoracodorsal and medial pectoral nerve transfer to the musculocutaneous nerve or grafting of C5 to the musculocutaneous nerve, for elbow flexion restoration. All patients underwent detailed preoperative evaluation, which included clinical and neurological examinations, electrophysiological investigation and neuroradiological studies. The final evaluation of achieved recovery of elbow flexion was done two years after surgery, using the British Medical Council scale.

RESULTS: We achieved functional satisfactory recovery (M3, M4, M5) in 29 of 30 patients (96.7%) in the common intraplexal nerve transfer group, and in 4 of 9 patients in the nerve grafting group (44.4.%). There was a significant statistical difference between these two groups in favor of common intraplexal nerve transfers over C5 grafting to the musculocutaneous nerve regarding functional recovery.

CONCLUSION: The results of our study concur with the findings of previous studies favoring intraplexal nerve transfers over nerve grafting in the restoration of elbow flexion in upper brachial plexus palsy. They reveal that intraplexal nerve transfers are clearly the primary treatment modality in cases of upper brachial plexus palsy without any sign of viable proximal C5 stump presence, while in cases of upper brachial plexus palsy with signs of viable proximal C5 stump the choice of the best treatment modality is still controversial.

KEYWORDS: Brachial plexus palsy, Elbow flexion recovery, Nerve grafting, Nerve transfer

INTRODUCTION

Traumatic brachial plexus injuries can have tremendous effects on function of the upper extremity (2,11,19). In recent years, with the development of high-speed vehicles and motor sports, the frequency of these injuries has been increasing (37). Supraclavicular traction injuries occur in 75% of the patients with brachial plexus injury (11,35). Around 55% of the supraclavicular injuries involve all five roots, resulting in a flail limb (total brachial plexus paralysis) (35). About 45% of upper brachial plexus injuries in adults involve the C5-C6 and/or C7 roots (35). Upper brachial plexus

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injuries leads to denervation of the brachialis, biceps, rotator cuff muscles and deltoid. If C7 root is involved, it results in loss of forearm musculature and triceps (1,10).

Functionally, the restoration of elbow flexion is the priority in adult patients, followed by the restoration of shoulder abduction and stability, and then by the external rotation of the shoulder (10).

The treatment options include neurolysis, direct nerve repair, nerve grafting, and nerve transfer (11,19,20). However, since the majority of these injuries are traction or avulsion injuries, nerve transfer is usually the only option for satisfactory recovery. Nerve transfer is a surgical method for restoring nerve function using a functionally less important but healthy nerve to re-innervate the injured nerve which is functionally more important. This method involves re-direction of an intact motor nerve from one muscle to the distal undamaged portion of a nerve from another, effectively bypassing the injured nerve segment. Neurolysis can be effective when the nerve damage or incomplete recovery is a result of developing scar tissue, or to alleviate pain (37). Direct nerve repair and nerve grafting are not appropriate for these kinds of injuries because in the majority of cases they involve long segments of the trunks, divisions or cords, and may be segmental in nature. Long grafts often cannot be acquired, and most authors indicate that shorter grafts (<10 cm) result in more favorable outcomes (35). But in infraganglionary brachial plexus lesions, with viable proximal stump C5, we should consider using it as a donor for nerve grafting. Usually, the medial cutaneal antebrachial nerve or the sural nerve are used as grafts. According to functional priorities, the targeted nerves to be re-innervated are the musculocutaneous nerve, the axillary nerve and the suprascapular nerve.

The restoration of elbow flexion may be obtained through the re-innervation of the musculocutaneous nerve or its branches to the biceps and/or brachialis muscles.

An optimal method for nerve transfer has not yet been established. Generally, there are two types of donors: *extraplexal*, including intercostal, phrenic, spinal accessory, motor branches of the cervical plexus, or collateral C7 spinal nerve, and *intraplexal*, including proximal spinal nerve stumps or collateral motor branches of the brachial plexus and the fascicles of the ulnar and median nerves, whereby the latter two are distal forms of the intraplexal nerve transfer (26). According to recent reports, fascicular and nerve transfers using collateral branches of the brachial plexus yield superior results in comparison to nerve grafts (5,31), although graft repair can also give favorable results, especially at the level of cords and their outflows (10).

The main advantages of nerve transfer in comparison to graft repair include (10,28,29):

- Distal section of the donor and recipient nerves,
- Anastomosis close to the target muscle with increased number and shorter distance for regenerating axons,
- Usually no need for the interposition of nerve grafts,
- Surgery performed outside the zone of injury and scarring, and
- Earlier and improved re-innervation.

However, there are also some disadvantages of nerve transfer, including donor site morbidity, especially when the innervated muscle has a suboptimal function, the fact that this muscle is no more suitable for transfer, and the need for central re-education (10,29).

The aim of this study is to present 39 cases of common intraplexal nerve transfers and nerve grafting for the re-innervation of the musculocutaneous nerve, and to compare the results of nerve grafting vs. common infraclavicular intraplexal nerve transfer in elbow flexion restoration.

■ MATERIAL and METHODS

Patient Selection and Preoperative Evaluation

This study included 39 patients with upper brachial plexus palsy who were operated at the Clinic for Neurosurgery, Clinical Center of Serbia, in the period from 2004 to 2014, using common intraplexal nerve transfer, i.e. the Oberlin procedure and thoracodorsal and medial pectoral nerve transfer to the musculocutaneous nerve (30 cases), or grafting of C5 to the musculocutaneous nerve (9 cases), for elbow flexion restoration.

All patients underwent detailed preoperative evaluation, which included clinical and neurological examination, electrophysiological investigation and neuroradiological studies.

The choice of appropriate nerve transfer for every patient was made having in mind the following characteristics:

- An expendable nerve with muscle strength of at least M4;
- A nerve near the motor end plate of the target muscle;
- A nerve with many pure motor axons and with a preferable donor to recipient nerve axon count ratio > 0.7;
- An appropriate size match between the donor and the recipient nerve;
- Synergistic action with the target muscle to facilitate motor re-education, although this can also be achieved with an antagonistic muscle.

The choice of appropriate C5 proximal stump as a donor for C5-musculocutaneous nerve autotransplantation was made having in mind the following characteristics:

- Preserved function of the proximal muscles (m. levator scapulae, m. rhomboideus, m. serratus anterior);
- Positive Tinnel sign and negative axon reflex;
- Absence of sensory nerve action potentials in the clinically paralyzed and anesthetic arm;
- Presence of N9 (clavicular) and absence of N13 (cervical) and N20 (cortical) responses in performing somatosensory evoked potentials (SSEP);

- Absence of traumatic pseudomeningocele at the C4-C5 and C5-C6 levels;
- Registration of compound nerve action potentials (CNAP) on C5 during intraoperative transcranial stimulation.

Surgical Procedures

In all 30 cases of common infraclavicular nerve transfers, we achieved tension free direct coaptation with 10.0 sutures and fibrin glue. In the Oberlin procedures, we connected one fascicle of the ulnar nerve to the branch of the musculocutaneous nerve to the biceps brachi muscle. In thoracodorsal nerve and medial pectoral nerve transfers, we connected these nerves to the main trunk of the musculocutaneous nerve.

In the 9 grafting cases, in order to avoid diameter mismatch and to make the cross-sections of the nerves compatible, we used the medial antebrachial cutaneous nerve and the sural nerve in a double grafting procedure for direct transplantation of C5 to the musculocutaneous nerve, with the use of 10.0 suturing and fibrin glue. The average length of the nerve grafts was 10.0±1.3 cm.

Postoperative Examination

Physical treatment was conducted in all patients after surgery. Final evaluation of the achieved recovery of elbow flexion was done two years after surgery. The patients were evaluated using the British Medical Council Scale (M0-M5) (27) (Table I).

Statistics

Methods used for statistical analysis in this study were methods of descriptive and analytical statistics. The choice of methods of analytical statistics (parametric and non-parametric tests) depended on the nature of the observed characteristics. For attributive features, Pearson's X^2 test was used, with Fisher's correction in the case of low prevalence of the investigated characteristics, and for statistical analysis of numerical characteristics the Student t test was used. Examined variables were considered statistically significant if the probability of risk for accidental difference between empirical and theoretical values was less than 0.05 ($p < 0.05$).

■ RESULTS

Among the 39 patients included in the study, there was a distinct male preponderance, 34 males vs. 5 females. In 24 cases, the injured arm was the dominant one, while in the remaining 15 cases the injured arm was non-dominant.

There were 34 (87.2%) cases with supraclavicular and 5 (12.8%) cases with infraclavicular brachial plexus lesions.

In terms of age, two thirds of patients were young and healthy before the injury (66.7% under 40 years of age). Thereby, the majority of patients, 36 of them, were in the group of working population (18-60 years old) (Table II).

In 20 cases (51.3%) there occurred extensive associated injuries, in 7 cases (17.9%) there were minor associated injuries, and the remaining 12 cases (30.8%) had no associated injuries (Table III). Extensive injuries included bone injuries requiring surgical treatment, injuries to major blood vessels and soft tissue injuries with defects. Minor injuries included bone injuries not requiring surgical treatment.

Concerning the timing of surgical treatment, the majority of patients (22 patients) were treated in the period of 3 to 6 months after injury (56.4%) (Table IV).

As for the distribution of the surgical procedures used, the Oberlin procedure was performed in 12 cases (30.8%), grafting of C5 to the musculocutaneous nerve in 9 cases (23.1%), pectoralis medialis nerve transfer in 17 cases (43.6%), and thoracodorsal nerve transfer in only one case (2.6%) (Table V).

Concerning the purpose of this study, we divided patients in two groups: the first group of 30 patients in whom we performed common intraplexal nerve transfer (pectoral medial nerve transfer, thoracodorsal nerve transfer and Oberlin procedure) and the second group of 9 patients in whom we performed nerve grafting of C5 to musculocutaneous nerve (Table VI).

The achieved recovery of elbow flexion was as follows: perceptible contraction in proximal and distal muscles (M2) in 6 patients (15.4%), full act against gravity (M3) in 11 patients (28.2%), power to act against strong resistance (M4) in 13 patients (33.3%), and full recovery of all muscles (M5) in 9 patients (23,1%). There were no patients without noted recovery (M0/M1) (Table VII).

In order to compare the elbow flexion restoration results of common infraclavicular intraplexal nerve transfer vs. nerve grafting, we first conducted a statistical analysis for the two respective groups of patients with regard to other factors that could influence the treatment outcome: age, the timing of surgery, and the extensity of associated injuries. The analysis showed that there was no significant statistical difference between the intraplexal nerve transfer and nerve grafting groups concerning these additional factors – specifically, regarding age: $p=0.438$, $p>0.05$; regarding the timing of surgery: $p=0.665$, $p>0.05$; and regarding the extensity of associated injuries: $p= 0.103$, $p>0.05$.

As shown in Table VI, we achieved functional satisfactory recovery (M3, M4, M5) in 29 of 30 patients (96.7%) in the common intraplexal nerve transfer group, and in 4 of 9 patients in the nerve grafting group (44.4.%). In other words, with regard to functional recovery, there was a statistically significant difference between these two groups ($p=0.001$; $p<0.05$), in favor of common intraplexal nerve transfers over C5 grafting to the musculocutaneous nerve.

Comparing each procedure individually (Table VII), the highest percentage of satisfactory functional recovery (M3,M4,M5) was achieved with Oberlin procedure and thoracodorsalis nerve transfer (100%), followed by pectoral medial nerve transfer (94%), whereby with C5 to musculocutaneous nerve grafting it was 44.4%.

Specifically, regarding the comparison between the C5 nerve grafting to the musculocutaneous nerve and each individual common intraplexal nerve transfer in elbow flexion restoration, the following results were obtained:

Table I: Patient Evaluation Using the British Medical Council Scale

Dissatisfactory functional recovery	M0	No visible contraction
	M1	Visible muscle contraction, but not active movement of the limb
	M2	Active movement, but not against gravity
Satisfactory functional recovery	M3	Active movement against gravity
	M4	Active movement against gravity and resistance
	M5	Active movement against full resistance

Table II: Age of Patients in Our Study

Age (years) group	Intraplexal nerve transfer	Nerve grafting	Total
Younger than 10	1	0	1 (2.6%)
11-20	2 (66.7%)	1 (33.3%)	3 (7.7%)
21-30	10 (76.9%)	3 (23.1%)	13 (33.3%)
31-40	6 (66.7%)	3 (33.3%)	9 (23.1%)
41-50	8	0	8 (20.5%)
51-60	3 (60%)	2 (40%)	5 (12.8%)

Table III: Extent of Additional Injuries

	Intraplexal nerve transfer	Nerve grafting	Total
Extensive injuries	16 (80%)	4 (20%)	20
Minimal injuries	7	0	7
No additional injuries	7 (58.3%)	5 (41.7%)	12

Table IV: Timing of Surgery

Timing of surgery	Intraplexal nerve transfer	Nerve grafting	Total
3-6 weeks	2	0	2 (5.1%)
Less than 3 months	5 (62.5%)	3 (37.5%)	8 (20.5%)
3-6 months	18 (81.82%)$^{0.006**}$	4 (18.18%)	22 (56.4%)
6-12 months	4 (66.7%)	2 (33.3%)	6 (15.4%)
More than 1 year	1	0	1 (2.6%)

Table V: Types of Surgical Treatment, Regarding the Level of the Lesion

	Oberlin procedure	C5 to musculocutaneous and axillary nerve	Pectoralis medialis nerve transfer	Thoracodorsal nerve transfer
Supraclavicular	11 (91.7%)$^{0.011*}$	7 (77.8%)	15 (88.2%)$^{0.012*}$	1
Infraclavicular	1 (8.3%)	2 (22.2%)	2 (11.8%)	0
Total (%)	12 (30.8%)	9 (23.1%)	17 (43.6%)	1 (2.6%)

Table VI: Recovery of Elbow Flexion in Different Types of Surgical Treatment

Type	No recovery (M0/M1)	M2	M3	M4	M5
Intraplexal nerve transfers	0	1 (3.3%)	10 (33.3%)	10 (33.3%)	9 (30.0%)
Nerve grafting	0	5 (55.6%)	1 (11.1%)	3 (33.3%)	0
Total (%)	0	6 (15.4%)	11 (28.2%)	13 (33.3%)	9 (23.1%)

Table VII: Recovery of Elbow Flexion Using Different Types of Nerve Transfers and Nerve Grafting

Type	No recovery (M0/M1)	M2	M3	M4	M5	Total (%) of recovery (M3,M4,M5)
Oberlin procedure	0	0	4 (36.4%)	3 (23.1%)	5 (55.6%)	12 (100%)
C5 to musculocutaneous nerve	0	5 (83.3%)	1 (9.1%)	3 (23.1%)	0	4 (44.4%)
Pectoral medial nerve transfer	0	1 (16.7%)	6 (54.5%)	6 (46.2%)	4 (44.4%)	16 (94%)
Thoracodorsal nerve transfer	0	0	0	1 (7.7%)	0	1 (100%)

- A statistically significant difference between C5 nerve grafting and the Oberlin procedure ($p=0.007$, $p<0.05$), in favor of the Oberlin procedure;
- A statistically significant difference between C5 nerve grafting and pectoral medial nerve transfer ($p=0.026$, $p<0.05$), in favor of the pectoral medial nerve transfer;
- No statistically significant difference between C5 nerve grafting and thoracodorsal nerve transfer ($p=0.493$, $p>0.05$); however, we had only one case with the thoracodorsal nerve transfer, so a more precise statistical analysis requires a bigger sample.

■ DISCUSSION

The musculocutaneous nerve contains approximately 6000 axons and up to 5000 of them are motor axons. The motor branch to the biceps muscle contains an average of 1840 axons and the motor branch to the brachialis muscle 1826 axons (29). Accordingly, these branches are ideal recipients in all distal nerve transfers. It should be emphasized that excellent results could be achieved through the re-innervation of the whole musculocutaneous nerve. This fact contributes to the important role of the biceps muscle in elbow flection, since the proximal muscle attracts the majority of axonal sprout.

Regardless of the method used in nerve transfer, the ideal timing has not yet been established. What is certain is that the target muscle should be re-innervated within the period of 12 to 18 months after injury in order to avoid irreparable atrophy and the loss of motor end plates. Therefore, there is a possibility for late distal nerve transfer.

Considering the biceps muscle as primarily forearm supinator and secondarily elbow flexor, and the brachialis muscle as the primary elbow flexor, Tung et al.(36) proposed separate neurotisation of these muscles to maximize the potential for restoration of strong function. However, it is not absolutely certain which of them is a better target for elbow flexion restoration (14). It should be noted that the re-innervated biceps muscle contributes to the shoulder stability and provides active external rotation due to the action of its long head.

Thoracodorsal Nerve Transfer

The thoracodorsal nerve derives from the posterior cord and receives fibers from the eighth, the seventh, and sometimes the sixth cervical nerves. It is a motor nerve that innervates the latissimus dorsi muscle. The mean surgically useable length of the nerve is 12.3 cm (from 8.5 to 19.0 cm). The diameter of the nerve ranges from 2.1 to 3 mm (24,26 27), with 1530 to 2479 myelinated fibers (24,26,27). Thus, the thoracodorsal nerve may be an excellent donor in motor nerve transfers.

The thoracodorsal nerve has a sufficient number of motor axons for the re-innervation of the biceps and brachialis muscles, without a need for neurolysis and exclusion or redirection of the lateral antebrachial cutaneous sensory nerve fibers (26,36). Accordingly, we consider that there is no demand for augmentation by additional nerve transfer to the brachialis muscle as proposed by Tung et al. (36). Nevertheless, nerve anastomosis should be done distally of the branches to the coracobrachialis muscle, because this muscle is not crucial for elbow flexion. In a greater number of cases, with extended upper brachial plexus palsy involving the C7 spinal nerve, or injuries to the middle trunk and posterior cord, the thoracodorsal nerve is not useful (26).

We consider that, in seriously weakened arm and shoulder movements, additional palsy of arm adduction and internal rotation due to the loss of the latissimus dorsi is a tolerable sacrifice (26,30,38). Likewise, Borrero (6), Novak et al. (21,26) and Tung et al. (26,36) did not register side effects from the denervation of the latissimus dorsi muscle. Richardson (23,26) achieved biceps muscle functional recovery in all four cases with two years delayed nerve repair. Also, Novak et al. (21,26) achieved re-innervation of the biceps muscle in all six cases applying a modified technique, i.e. independent transfer of the thoracodorsal divisions to the biceps and brachialis branches of the musculocutaneous nerve (26). They achieved M4 and M5 grades in their five cases. Finally, Tung at al. (36) used thoracodorsal nerve in re-innervation of the brachialis branch of the musculocutaneous nerve, and they achieved good results. In recent publications reporting the usage of the thoracodorsal nerve in the re-innervation of whole musculocutaneous nerve, 100% rate of useful functional recovery was obtained (23,26). In our study, we also obtained satisfactory functional recovery in 100% of the cases with the thoracodorsal nerve transfer to the musculocutaneous nerve.

Medial Pectoral Nerve Transfer

The medial pectoral nerve originates from the anterior part of the inferior trunk and gains nerve fibers from the C8 and Th1 spinal nerves. This motor nerve is also engaged into the function of the upper extremity and it innervates the sternal part of the pectoral major muscle (13,26). The nerve ends in the pectoralis muscle with two or three branches (26,38).

The surgically useable length of the nerve ranges from 30 to 78 mm (13). Still, this length may be expanded by dissecting terminal branches and their section close to the pectoral muscle. The mean diameter of the medial pectoral nerve ranges from 1.5 to 2.5 or 2.7 mm (13,24), with the number of motor fibers from 1170 to 2140 in the main trunk (24) and 400 to 600 fibers in a muscular branch (14). Thus, the medial pectoral nerve is an important donor for motor nerve transfer, particularly considering the number of motor nerve fibers.

There are three main surgical problems in performing anastomosis, especially to the musculocutaneous nerve; variations in the diameter of the nerves, the inadequate length of the medial pectoral nerve for direct anastomosis, and its functional preservation (26).

In case of diameter mismatch, some authors have sutured the medial pectoral nerve to the fascicle of the musculocutaneous nerve, or have used an epineural suture over a part of the musculocutaneous nerve cross-sectional area (13). In the larger part of our cases, we removed the fascicular epineurium of the recipient nerve and bundled the medial pectoral nerve with the branch of the pectoral ansa in order to solve this problem. We have also bundled several branches of the medial pectoral nerve in a common trunk using fibrin glue (25,26).

The ideal nerve transfer includes direct nerve anastomoses among the donor and recipient nerves. But, in one third of the cases, the length of the medial pectoral nerve is insufficient for tension-free direct anastomosis with the musculocutaneous nerve, with the average length of gap approximately 15 to 20 mm (3,24,26). This problem may be solved with the retrograde split of the musculocutaneous nerve into the lateral cord, the distal section of the medial pectoral nerve branches (13), the dissection of the nerve trunk from its branch to the pectoral ansa (34), and the section of the arcade between the pectoral nerves (13,25,38).

Similarly to the transfer of the thoracodorsal nerve, we consider that additional palsy of arm adduction and internal rotation is tolerable in patients with seriously weakened shoulder function (26-28). Moreover, in cases with predominant innervation from the C7 spinal nerve root, the function of synergistic muscles such as the teres major muscle may be partly maintained. Also, a part of function of the pectoral muscles may be saved due to multiple innervation model of the pectoralis major muscle, since the usual origin of the lateral pectoral nerve is from the C5 to C7 spinal nerves, with the mean percentage of supply for pectoral muscles from the C7 spinal nerve amounting to 50%. Functional preservation is also possible by distal sectioning and sparing some of the branches (13). Our results, as the results in some other published articles, showed that the remaining branch or branches mostly produce strong contractions of the pectoral major muscle (13). End to side neurorraphy is also possible for functional protection of the donor nerves (3), but only Wellons et al. applied this technique in one case of the medial pectoral to the musculocutaneous nerve transfer (26,38).

Brandt and Mackinnon used a modified technique of anastomosis distal to the branches to the coracobrachialis muscle, in which they divided and re-directed the lateral antebrachial cutaneous nerve to the biceps muscle (21,26). Using this technique, they avoided wasting motor nerve fibers for the re-innervation of the functionally unimportant coracobrachialis muscle and their ingrowth into sensory endoneural tubules, thus achieving anastomosis as close as possible to the biceps muscle branch. Tung et al. used this nerve for the re-innervation of the brachialis branch of the musculocutaneous nerve in combination with the Oberlin procedure, and achieved re-innervation that was comparable to that of the biceps muscle in all six cases (26,36). They stated that neurolysis and exclusion of the sensory component was not necessary with this method. Although the homolateral use of the medial pectoral nerve is controversial because the potential absence of arm adduction may be very disabling, the obtained useful functional recovery of elbow flexion in 80% to 100% of cases (averaging at about 90% according to the majority of reports) supports the use of this method. In our study, we obtained satisfactory functional recovery in 94% of the cases with the medial pectoral nerve transfer to the musculocutaneous nerve.

Fascicular Nerve Transfer – Oberlin Procedure

There are three modalities of fascicular nerve transfer:

- Ulnar nerve fascicle to the biceps muscle nerve branch, introduced by Oberlin et al. in 1994 (22),
- Partial median nerve fascicle transfer to the same branch, introduced by Sungept et al. in 2003 (32),
- Double fascicular nerve transfer (15), i.e. a combination of the Oberlin procedure and the median nerve fascicle transfer to the brachialis muscle nerve branch, introduced by Mackinnon et al. in 2005 (18).

The general characteristics of fascicular nerve transfers are the following:

- A large number of motor fibers,

- No or minimal axonal mixing,
- No wastage of any donor nerve fibers into the sensory part of the musculocutaneous nerve,
- Anatomical proximity to the recipient nerve branches,
- The possibility of a distal tension free direct nerve anastomosis,
- Rare and usually transient deterioration of hand function including the worsening of sensitivity and decrease in handgrip and lateral pinch strength,
- More physiological reconstruction with easier cortical re-education,
- Early beginning and completion of recovery.

The possible problems with fascicular nerve transfer include the following:

- The fascicles supplying purely motor branches are less common than the mixed ones and they can be found usually near the branching points (1,32),
- Preoperative ulnar or median nerve deficit argues against their fascicle transfer (1,32),
- Proper selection of donor fascicles may require dissection over several centimetres that may be limited due to plexus formation.

In the Oberlin procedure, one or two fascicles (approximately 10% of the ulnar nerve cross-sectional area) innervating the flexor carpi ulnaris muscle are commonly used as the donor (22). The average number of axons per ulnar nerve fascicle is 1318 (29), which is sufficient for the re-innervation of the biceps muscle nerve branch. However, Teboul et al. (34) used three fascicles, and Ferraresi et al.(8) used 25% of the ulnar nerve cross-sectional area in the transfer to the entire musculocutaneous nerve with similar results. The rates of recovery range from 75% to 94% in the majority of publications (7-9,12,16,17,30,31,33,34). In our study, we obtained satisfactory functional recovery in 100% of the cases with the Oberlin procedure.

C5 Nerve Grafting to the Musculocutaneous Nerve

The proximal stump of C5 is used as a donor to the musculocutaneous nerve. According to the functional priorities, the most common recipient nerves are the upper and trunk, its anterior and posterior division, the musculocutaneus nerve, the axillary nerve and the suprascapular nerve.

We have to emphasize that there is very little data available regarding the comparison between the two strategies for grafting from the proximal stump of C5. The first strategy includes grafts attached to the proximal divisions of the brachial plexus (anterior division of the upper trunk), whereby grafts are shorter but the dispersion of regenerating axons is larger. The second strategy includes grafts attached to the terminal branches of the brachial plexus (the musculocutaneous nerve), whereby grafts are longer but the dispersion of regenerating axons is smaller.

Bentolila et al. presented that nerve grafts longer than 7.2 cm were accompanied with the worse results related to short grafts; long nerve grafts to the musculocutaneous nerve may be subject to the attenuation of nerve regeneration potential, especially if performed more than six months after injury (4). In our study, we performed grafting of the C5 to the musculocutaneous nerve. The average length of nerve grafts was 10.0±1.3 cm. We obtained satisfactory functional recovery in 44.4% of the cases.

■ CONCLUSION

Previous studies have shown that nerve transfers give better results than nerve grafting in treating patients with upper brachial plexus palsy (10). Our study also favors intraplexal nerve transfers over nerve grafting in elbow flexion restoration in upper brachial plexus palsy. Namely, we achieved satisfactory functional recovery in 29 of 30 patients (96.7%) in whom we performed common intraplexal nerve transfers, while we achieved functional satisfactory recovery in 4 of 9 patients (44.4%) in whom we performed nerve grafting from C5 to the musculocutaneous nerve.

Concerning elbow flexion recovery, our study shows that there is a significant statistical difference between the two groups of patients – one with nerve grafting and the other with common intraplexal nerve transfers – in favor of common intraplexal nerve transfers ($p=0.001$; $p<0.05$).

More specifically, in cases of upper brachial plexus palsy without any sign of viable proximal C5 stump presence, intraplexal nerve transfers are the primary treatment modality without any doubt. However, cases of upper brachial plexus palsy with signs of viable proximal C5 stump are still controversial regarding the choice of the best treatment modality.

On the one hand, nerve transfers afford more regenerating nerve fibers, a shorter distance which they have to pass and fewer suture lines which they have to overcome, so chances to obtain satisfactory functional recovery are higher (especially in cases presented six months or more following the injury), but they are accompanied with additional neurological deficit due to the harvesting of a functional intact nerve as a donor. On the other hand, nerve grafting – in spite of additional suture junction, the devascularized autogenous graft, and/or the required extra regeneration distance (which diminished outcomes) – could afford satisfactory functional recovery without any additional neurological deficit and without any need for brain plasticity and central re-education of movements.

In sum, despite evident advantages of nerve transfers in elbow flexion restoration, in cases of upper brachial plexus palsy with viable proximal C5 stump, we still need to think about which method to use – a particular nerve transfer, nerve grafting, or a combination thereof. The choice of treatment modality largely depends on the surgeon's experience and his/her preferred method.

Our study provides a contribution towards dealing with this dilemma, in view of the multiple treatment modality choices. Clearly, the number of patients included in this study (operated on over a period of 10 years) is insufficient for an elaborate statistical analysis, but the results may serve as a useful input for further investigation. Only a few centers in the world have enough patients to carry out a single-center comprehensive comparison of surgical reconstruction. Hence the best study design to compare nerve grafts and nerve transfers would be a prospective, multicenter randomized trial of large numbers of patients. Thereby, correlation of results from different centers would be better if joint-specific range-of-motion data and manual muscle strength grading could be expressed in the same way in all studies (10).

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