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CONTROVERSIES IN NERVE TRANSFERS FOR UPPER BRACHIAL PLEXUS PALSY DUE TO TRACTION INJURIES

Abstract: *Background:* Nerve transfers in cases of directly irreparable, or high level extensive brachial plexus traction injuries are performed using a variety of donor nerves with various success but an ideal method has not been established.

The purpose of this study was to analyze the results of nerve transfers in patients with traction injuries to the brachial plexus using the thoracodorsal and medial pectoral nerves as donors.

Methods: This study included 40 patients with 25 procedures using the thoracodorsal nerve and 33 procedures using the medial pectoral nerve as donors for reinnervation of the musculocutaneous or axillary nerve.

Results: The total rate of recovery for elbow flexion was 94.1%, for shoulder abduction 89.3%, and for shoulder external rotation 64.3%. The corresponding rates of recovery using the thoracodorsal nerve were 100%, 93.7% and 68.7%, respectively. The rates of recovery with medial pectoral nerve transfers were 90.5%, 83.3% and 58.3% respectively.

Conclusion: According to our findings, nerve transfers using collateral branches of the brachial plexus in cases with upper palsy offer several advantages and yield high rate and good quality of recovery.

INTRODUCTION

In the past, nerve transfers were the treatment of choice in cases with spinal nerve root avulsion, or those with directly irreparable proximal lesions, i. e. very proximal or injuries without a nerve available for grafting. Recently, indications for nerve transfers have been extended to high level nerve injuries with extensive gap for grafting and delayed nerve repairs, significant bony or vascular injuries in the region of direct repair and previously failed proximal nerve repair. The main advantage of this procedure over nerve grafting is a conversion of proximal high-level injury to a low-level one.

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Nerve transfers have been attempted using a variety of donor nerves, but an ideal method has not been established. In general, there are two types of donors: extraplexal, including intercostal, spinal accessory, phrenic, 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 or fascicles of the ulnar and median nerves. In fact, the latter presents a distal form of the classic intraplexal nerve transfer.

The aim of this study was to analyze characteristics and results of nerve transfers in patients with traction injuries to the brachial plexus using the thoracodorsal, medial pectoral nerves, nerve branch to triceps, ulnar or median nerve fascicles as donors.

METHODS

During the past 30 years, since January 1980, we performed nerve transfer using collateral branches of the brachial plexus as donors in 44 patients with upper palsy due to traction injury. The number of followed up patients was 40, or more precisely 33 with nerve transfers using the medial pectoral nerve, and 29 using the thoracodorsal nerve as donor. Both nerves were used simultaneously in 22 of the followed up patients. The age of the followed up patients ranged from 9 do 55 years, with 27 (67.5%) being less than 30 years of age.

In these 44 patients we performed 38 reinnervations of the musculocutaneous nerve, 13 using the thoracodorsal nerve and 25 using the medial pectoral nerve as donors, and 33 reinnervations of the axillary nerve, 20 using the thoracodorsal nerve and 13 using the medial pectoral nerve as donors. Both nerves were used simultaneously in 24 patients, and in the remaining cases nerve transfers using these collateral branches were combined with the spinal accessory or intercostal nerve transfers.

The results of the surgery were related to the donor and recipient nerves according to the modification of grading system which we used in our previous reports 6, as follows: 1) „bad" denotes no movement or weightless movement; 2)„fair" denotes movement against gravity with the ability to hold position, active abduction up to 45 degrees, elbow flexion up to 90 degrees, the range of external rotation from full internal rotation up to 45 degrees; 3) „good" denotes movement against resistance with the ability to repeat movements in succession, active abduction of more than 45 degrees, full range elbow flexion, external rotation up to 90 degrees. 4) „excellent" denotes near normal function with external rotation over 90 degrees.

Fair, good, and excellent results were considered to represent recovery. According to our grading system, recovery roughly corresponds to M^2 or more grade of recovery according to the Louisiana State University Medical Center grading system, and to M^3 or more grade of recovery according to the British Medical Research Council system. The quality of recovery was estimated and the basis of proportions of excellent and good versus fair results. The follow-up period was at least two years.

RESULTS

Functional recovery of elbow flexion was obtained in 32 (94.1%) out of 34 nerve transfers in total, with good quality in 25 (78.1%) of 32 functionally useful transfers. Using the thoracodorsal nerve as donor we obtained recovery in all 13 cases, with good quality of recovery in 12 (92.3%) of them (Table 1). Using the medial pectoral nerve as donor the rate of recovery was somewhat lower, i. e. 19 (90.5%) of 21 cases, and the quality of recovery was significantly lower, 13 (68.4%) excellent and good results among recoveries (Table 2).

Shoulder abduction recovery was obtained in 25 (89.3%) out of 28 nerve transfers in total. The quality of recovery was also lower compared to that for elbow flexion. Excellent and good results were obtained in 16 (64%) of 25 recovered cases. Using the thoracodorsal nerve as donor we achieved functional recovery in 15 (93.7%) of 16 cases with good quality of recovery in only 9 (60%) of 15 recoveries (Table 1). The rate of medial pectoral nerve recovery was somewhat lower, 10 (83.3%) of 12 transfers, but the quality of recovery was better, 7 (70%) excellent and good results among recoveries (Table 2).

Some shoulder external rotation recovery was obtained in 18 (64.3%) of 28 nerve transfers to the axillary nerve. Excellent and good results were obtained in

Table 1. The results of 29 nerve transfers using the thoracodorsal nerve as donor

OUTCOMES (number of cases)								
DONOR NERVE	Musculocutaneous				Axillary			
	Bad	Fair	Good	Excellent	Bad	Fair	Good	Excellent
Thoracodorsal	/	1	6	2	/	5	4	1
Thoracodorsal and intercostal	/	/	1	1	1	/	1	/
Thoracodorsal and subscapular or long thoracic	/	/	2	/	/	1	2*	1
Total	/	1	9	3	1	6	7	2

* one case combined with the long thoracic nerve

Table 2. The results of 33 nerve transfers using the medial pectoral nerve as donor

OUTCOMES (number of cases)								
DONOR NERVE	Musculocutaneous				Axillary			
	Bad	Fair	Good	Excellent	Bad	Fair	Good	Excellent
Medial pectoral	1	6	7	3	2	3	2	1
Medial pectoral and spinal accessory or intercostal	1	/	1	2	/	/	3	1
Total	2	6	8	4	2	3	5	2

Table 3. The results of thoracodorsal and medial pectoral nerve transfers regarding shoulder external rotation

	RESULT			
DONOR NERVE	Bad	Fair	Good	Excellent
Thoracodorsal	2	4	2	2
Thoracodorsal and intercostal	1	1		
Thoracodorsal and subscapular or long thoracic	2	2		
Medial pectoral	3	3	2	
Medial pectoral and intercostal or spinal accessory	2	2		
Total	10	12	4	2

only 6 (33.3%) of 18 recoveries and were related to the good quality of recovery of the elbow flexion and shoulder abduction. The rates of recovery were similar for both nerves, 11 (68.7%) of 16 transfers using the thoracodorsal nerve, and 7 (58.3%) of 12 transfers using the medial pectoral nerve. The quality of recovery was also similar, 4 (36.3%) excellent and good results for the thoracodorsal nerve and 2 (28.6%) for the medial pectoral nerve among recoveries (Table 3).

DISCUSSION

Donor nerves

Nerve transfers using collateral branches of the brachial plexus and fascicles of ulnar and median nerves present a distal form of the intraplexal nerve transfer that generally yield better results because of the higher number of motor fibers and more physiologic reconstruction. However, these offer some advantages to the classical intraplexal transfer, such as insignificant axonal mixing, the absence of mass or cross innervation, anastomosis close to the target muscle and more precise evaluation of donor nerve functional validity compared to that of the proximal nerve stumps.

Collateral branches of the brachial plexus, particularly the thoracodorsal and medial pectoral nerves, are voluntary motor nerves with a significant number of motor fibers, close functional relationship with upper arm nerves, better cortical reintegration owing to central plasticity based on preexisting central and medullary synaptic connections, anatomic proximity to the recipient nerves that enables tension free direct anastomosis or rarely anastomosis using short nerve grafts close to motor end plate of the target muscle. These nerves do not fulfill some other criteria, including the criterion that a motor donor nerve should be expendable or redundant, without significant diameter mismatching with the recipient nerve and preferably innervating synergistic muscles with the target muscle. These problems are especially important for the use of the medial pectoral nerve, but they may be overcome, at least partially, as we shall see later.

There are three possibilities for this type of nerve transfer. (1) Oberlin procedure (1994) consisting in the ulnar nerve fascicle transfer to the biceps muscle branch, (2) partial median nerve fascicle transfer to the same branch (Sungpet et al, 2003), and (3) double fascicular transfer, meaning combination of Oberlin procedure and median nerve fascicle transfer to the brachialis muscle branch. The general advantages of these transfers are (1) large number of nerve fibers, 2700 to 3500 per fascicle (Schreiber et al., 2014), (2) anatomical proximity to the recipient branches, (3) possibility for direct nerve anastomosis, (4) rare deterioration of hand function and (5) earlier time for beginning (3 to 5 months) and completion of functional recovery.

Functional priorities

The first priorities in brachial plexus repair are restoration of full range and strong elbow flexion, shoulder stability, active arm abduction and some external rotation. Recovery of all functions is equally important since these enable elbow movements through a more functional range. The recovery of elbow flexion may be achieved through reinnervation of the musculocutaneous nerve using different technical methods. Since the biceps muscle acts as a primary forearm supinator and secondarily provides elbow flexion, and the brachialis muscle is the primary muscle providing elbow flexion, (Tung et al, 2003) proposed separate neurotization of both muscles in order to maximize the potential for recovery of strong function. On the other hand restoration of shoulder function is somewhat controversial. Several authors recommended reinnervation of the suprascapular nerve since the supra- and infrascapular muscles are important for initiation of the arm abduction and some external rotation.

In a significant number of our cases we obtained good arm abduction and some external rotation reinnervating only the axillary nerve. This could be explained by reinnervation of the teres minor and posterior fibers of the deltoid muscle that act as shoulder external rotators. Furthermore, the reinnervated biceps contributes to shoulder stability through its long head and produces some active external rotation. Probably the best solution is dual nerve transfer to both the suprascapular and axillary nerves. However, the first muscle to be reinnervated attracts a majority of axons and in this case the supraspinatus reduces the potential for reinnervation of the external rotator, the infraspinatus muscle.

The thoracodorsal nerve

The thoracodorsal nerve is a motor nerve that originates from the posterior cord and receives nerve fibers from the seventh, eight, and sometimes sixth cervical nerves. More than 52% of motor fibers originate from the C 7 nerve root. This nerve has cerebral centers integrated into the function of the upper extremity and innervates the latissimus dorsi muscle. The mean surgically useable length of the nerve is 12.3 cm with a range of 8.5 to 19.0 cm. The diameter of the nerve ranges from 2.1 to 3 mm. The number of myelinated fibers ranges from 1,530 to 2,479. According to these characteristics, the thoracodorsal nerve may be considered as an excellent donor in motor nerve transfers.

The number of motor axons in the thoracodorsal nerve is sufficient for reinnervation of the biceps and brachialis muscles without a need for neurolysis and exclusion or redirection of the lateral antebrachial cutaneous sensory nerve fibers. Similarly, we think that there is no need for augmentation by additional nerve transfer to the brachialis muscle. However, nerve anastomosis should be done distally to the branches to the coracobrachialis muscle since this is not important for elbow flexion and should not be reinnervated. It should be emphasized that in the majority of cases with extended upper brachial plexus palsy involving the C 7 spinal nerve, or injuries to the middle trunk and posterior cord, the thoracodorsal nerve is not functional.

Regarding functional deficit after thoracodorsal nerve section, we believe that additional palsy of arm adduction and internal rotation due to the loss of the latissimus dorsi in severely disabled shoulder and arm movements presents an acceptable sacrifice. Similarly, Borrero (2007), Novak et al. (2002) and Tung et al. (2003) did not register ill effects from the denervation of the latissimus dorsi muscle. We obtained functional recovery in all 13 cases for the musculocutaneous nerve, and in 15 (93.7%) of 16 cases for the axillary nerve. Our results are supported by those published by Richardson (1997), who obtained functional recovery of the biceps muscle in all four cases with nerve repair delayed for two years, as well as by Novak et al. (2003), who reported successful reinnervation of the biceps muscle in all six cases using a modified technique, i. e. separate transfer of the thoracodorsal divisions to the biceps and brachialis branches of the musculocutaneous nerve.

Our results concur with those published by Borrero (2007) and Haninec et al. (2005). The results of thoracodorsal nerve transfer to the axillary nerve are less impressive, especially regarding the quality of recovery, probably due to the functional complexity of the shoulder abduction, the role of the supraspinatus muscle that is not reinnervated in these cases, and essentially antagonistic function of the latissimus dorsi muscle, although this could be successfully retrained.

Finally, the use of the thoracodorsal nerve will preclude the use of the latissimus dorsi muscle for secondary procedures.

The medial pectoral nerve

The medial pectoral nerve is a motor nerve that derives from the anterior division of the inferior trunk and receives nerve fibers from the 8^{th} cervical and the 1^{st} thoracic nerves. This nerve has also cerebral centers that are integrated into the function of the upper extremity and innervates with several branches the sternal part of the pectoralis major muscle.

Surgically useable length of the medial pectoral nerve ranged from 30 to 78 mm. However, this length may be increased by dissecting terminal branches and their section close to the pectoral muscle. The mean diameter of the nerve ranges from 1.5 to 2.5 or 2.7 mm. The number of motor fibers ranges from 1,170 to 2,140 in the main trunk and may reach 400 to 600 fibers in a muscular branch. The above mentioned branch of the pectoral ansa contains 330 to 440 nerve fibers. These characteristics make the medial pectoral nerve a valuable donor for motor nerve transfer, especially with regard to the number of motor fibers.

There are three main surgical problems in performing anastomosis with the axillary and especially the musculocutaneous nerve. These are the large discrepancy in the diameter of the nerves, the insufficient length of the former for direct anastomosis, and its functional preservation.

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 the part of the musculocutaneous nerve cross-sectional area. In the majority of 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 overcome this problem. More recently, we also bundled several branches of the medial pectoral nerve in a common trunk using fibrin glue. In cases in which these procedures were insufficient, we used an additional donor nerve, usually one intercostal or spinal accessory nerve. Sulaiman et al. (2009) used a combination of the medial pectoral nerve to the medial half of the musculocutaneous nerve transfer with grafting from the anterior division of lateral cord to the musculocutaneous nerve. This technique maximized axonal regeneration from two outflows, proximally repaired plexus elements, and the medial pectoral nerve transfer, and additionally they solved the problem of diameter mismatch.

The technically ideal nerve transfer allows direct nerve anastomoses between the donor and recipient nerves. According to some investigations, the length of the medial pectoral nerve is insufficient for tension-free direct anastomosis with the musculocutaneous nerve in approximately one third of cases. The average length of this gap is approximately 15 to 20 mm. This problem may be overcome in several ways, such as retrograde split of the musculocutaneous nerve into the lateral cord, distal section of the medial pectoral nerve branches, dissection of the nerve trunk from its branch to the pectoral ansa and sectioning the arcade between the pectoral nerves.

Similarly to transfer of the thoracodorsal nerve, we think that additional palsy of arm adduction and internal rotation is not as significant in patients with severely disabled shoulder function. Furthermore, in cases of predominant innervation from the C 7 spinal nerve root, the function of synergic muscles such as teres major may sometimes be partially preserved. In addition, some function of the pectoral muscles may be retained because of multiple innervation patterns of the pectoralis major muscle since the usual origin of the lateral pectoral nerve is from the C 5 to C 7 spinal nerves with the mean percentage of supply for pectoral muscles 50% from the C 7 spinal nerve. Functional preservation is also possible by distal sectioning and sparing some of the branches. According to our results and the results of some other published series, the remaining branch or branches usually produce strong contractions of the pectoralis major muscle.

Our results are in accordance with those published by Blaauw and Sloff (2003), Wellons et al. (2009), Haninec et al (2009) and Sulaiman et al (2009).

Nerve transfer of the triceps muscle branch

This type of nerve transfer was published for the first time by Leechavengvong et al. (2003). Originally, the branch innervating the long head of the triceps muscle was transferred to the anterior part of the axillary nerve in combination with transfer of the spinal accessory to the suprascapular nerve. The main advantages of this method are pure motor composition of the donor and anatomical proximity to the recipient nerve. Furthermore, muscle weakness is rare regardless of the chosen branch. However, this transfer should not be used in patients with the triceps muscle weakness or the C 7 spinal nerve injury because they may affect the quality of donor nerve and most importantly worsen function of the triceps muscle.

In published reports, functional recovery was obtained in all cases regardless the type of nerve transfer, isolated innervation of the axillary nerve (Bhandari et al, 2005; Dahlin, 2012) or combination with transfer of the spinal accessory to the suprascapular nerve (Leechavengvong et al, 2003; Agnantis et al, 2013).

Fascicular nerve transfers for elbow flexion

In Oberlin procedure, one or two fascicles i. e. about 10% of nerve cross-sectional area, innervating the flexor carpi ulnaris muscle (origin from the C 7 and C 8 spinal nerves) are used. In partial median nerve fascicle transfer, fascicles for the flexor carpi radialis muscle (origin from the C 6 and C 7 spinal nerves) or the palmaris longus muscle (origin from the C 7 and C 8 spinal nerves) are used. Finally, double fascicular transfer presents combination of the former two procedures.

The obtained rates of recovery ranged from 80% to 94.4% in Oberlin transfers (Leechavengvong et al, 1998; Grondin et al, 2004; Bhandari and Bathae, 2011; Baik Cho et al, 2014). For the median fascicle nerve transfer the results are similar with rates of recovery from 90% to 100% (Sungpet et al, 2003; Baik Cho et al, 2014; Al Qattan and Kharfy, 2014). Similar rates of recovery, 88% to 100% were obtained with double fascicular transfers (Mackinnon et al, 2005; Grondin et al, 2008; Ray et al, 2011). Our preliminary results with Oberlin procedure are similar with rate of recovery 80% (8 of 10 cases). It must be emphasized that there is no significant difference between single and double fascicular transfers (Martins et al, 2013).

Controversies in nerve transfers

The main controversies in nerve transfers for upper brachial plexus palsy are: (1) reanimation of shoulder abduction, (2) choice of donor nerves, (3) combined use of donor nerves and (4) choice between the nerve or musculotendinous transfer.

In shoulder reanimation the dilemma exists between transfer to the suprascapular either axillary nerve, or simultaneous use of both. Although, we obtained excellent results with transfers to the axillary nerve, probably the best solution is nerve transfer of the spinal accessory to the suprascapular nerve and transfer one of the collateral branches to the axillary nerve, as dual form of shoulder reanimation.

Regarding the choice of donor nerve there are several dilemmas such as (1) extra – or intraplexal donors, (2) spinal nerve stumps or collateral branches, and (3) collateral branches or fascicular transfers. According to our experience, nerve transfers using collateral branches of the brachial plexus are superior method, even to the fascicular transfers, especially regarding quality of recovery. Regardless, anastomosis to the whole trunk of the recipient nerve, good results are probably result of the tissue, end-organ and especially fascicular specificy, and most importantly of the role of neurotropism with critical distance for motor fibers of 5 mm that is achieved in direct anastomosis.

The main reasons for combined use of donor nerves were completion of the suture line and anastomosis close to the target muscles were nerve fibers for innervation of different muscles or their functional parts are focused. Although this method is at least controversial, we obtained 100% rate of recovery for elbow flexion and 88.8% for arm abduction with good quality. However, it is uncertain that these are result of combined or reinnervation by only one donor nerve.

Advantages of the nerve to the musculotendinous transfer, especially using the latissimus dorsi muscle are: (1) preservation of original biceps tendon and muscle fibers orientation and tension, (2) minimal target muscle dissection and consecutive formation of adhesions, (3) simplicity of procedure, (4) significant gain in operative time, and (5) average muscle strength following nerve transfers exceeds that obtained with musculotendinous transfers.

CONCLUSION

According to our experience and the results we obtained, nerve transfers using collateral branches of the brachial plexus in patients with upper palsy have several advantages: simplicity of the surgical procedure, significant gain in operative time, high rate of recovery, good quality of recovery in a significant number of cases, early signs of recovery, relatively short period for recovery completion, low rate of significant functional impairment due to loss in donor nerve innervation zone, generally. Finally, any combination of donor and recipient nerves does not preclude good result.

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