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Review

Transfer of the Medial Pectoral and Thoracodorsal Nerve in Cases with Upper Brachial Plexus Palsy: Controversies, Problems and Solutions

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SUMMARY

Two main priorities in restoring arm functions in brachial plexus injuries, regardless of their extension, are elbow flexion and shoulder functions. In cases with directly irreparable nerve injuries, nerve transfer is the only option for functional reconstruction. Nerve transfers have been attempted using different extraplexal and/or intraplexal donor nerves. Fortunately, in cases of upper brachial plexus palsy involving the C5, C6 and in some cases C7 spinal nerves, there is a wider choice of donors that include intraplexal collateral branches, fascicles of the ulnar and median nerves, and the triceps branches of the radial nerve. Our experiences are based on the use of the medial pectoral (MPN) and thoracodorsal (TDN) nerves, which could be used in the restoration of both functions, even simultaneously. The aim of this review, aside from an evaluation of already published results, is a discussion regarding controversies, some technical problems and their solutions. The main conclusion is that these transfers could be reliable methods in the restoration of upper arm functions, used both separately and in combination with other types of nerve transfers.

KEYWORDS

Brachial plexus; *Donor nerves*; *Medial pectoral nerve*; *Nerve transfer*; *Thoracodorsal nerve*

Introduction

Nerve transfers using the medial pectoral nerve (MPN) and thoracodorsal nerve (TDN) as donors in the reinnervation of the musculocutaneous nerve (MCN) or axillary nerve (AXN) present one of the modalities of infraclavicular nerve transfers in the functional restoration of upper brachial plexus palsy. The history of these nerve transfers dates back almost 100 years. In 1920, Vulpius and Stoffel published the use of the brachial plexus branches to the pectoral muscles as donors. In 1929, Foerster reported nerve transfer using the branches to the latissimus dorsi and subscapular muscles. Finally, in 1948 Lurja reported the use of MPN and TDN in the repair of upper trunk injuries[1,2]. Thereafter, there were no reports on this subject for several decades, until the late 1980s and early 1990s[3–6]. Recently, results of the use of MPN as a donor in the reinnervation of MCN[6–15] or AXN[8,15,16], and TDN in the reinnervation of MCN[15–19] or AXN[12,15,19-22] were reported sporadically and with a limited number of cases. Possible reasons could be existing controversies and surgical problems. The aim of this review was to clarify these subjects on the basis of personal experience and published research.

Methods

PubMed/Medline was searched for English-language literature including original research and a series of patients who were subjects of nerve transfer using MPN and/or TDN as donors in the reinnervation of MCN and/or AXN. MESH terms used in the search were “brachial plexus” in conjunction with the words “injury” or “trauma”, “nerve transfer”, “ medial pectoral nerve” and “thoracodorsal nerve” in the title. On this basis, a literature search was finally limited to 52 articles that included 15 systematic reviews published in the period after 1990. In addition to the donor and recipient nerves, inclusion criteria were (1) closed traction brachial plexus injury, (2) upper or extended brachial plexus palsy, (3) timing of surgery less than 12 months post-injury, (4) a follow-up period of at least 12 months and (5) a minimum of five published and analyzed cases. Exclusion criteria were (1) double-level nerve lesions, (2) the reinnervation of synergistic muscles from other donors, (3) combination with nerve grafting or tendon transfers, and (5) patients older than 65 years.

Analyses used donor and recipient nerves as independent variables. The significance of other independent variables, such are patients’ age and the timing of surgery, was not considered. Grades M3 or higher on the MRC Manual Muscle Testing Scale were considered as useful functional recovery for full-range elbow flexion and at least 90 degrees of arm abduction, with some range of external arm rotation. Grades M4 and M5 were considered as high-quality recovery. Because of a limited number of cases in some of the series, statistical analyses were performed using several tests, including Pearson’s Chi-square test, Fisher’s exact test and ANOVA, with a P-value of 0.05 or less as statistically significant.

Results

The results of MPN and TDN transfer to MCN or AXN were selected for comparative statistical analysis from 15 published systematic reviews/meta-analyses, which included 20 series of these nerve transfers (Tables 1 and 2). In the restoration of elbow flexion, the reported total rates of recovery ranged between 80% and 90.5% for MPN[6,8,9,11–15] and between 83.3% and 100% for TDN[15,18,19]. In the restoration of shoulder

TABLE 1 The results of medial pectoral nerve transfer

	Series Reference number	Rate of useful recovery (%) (n/total n)
Musculocutaneous nerve as a recipient	Brandt and Mackinnon, 1993[6]	4/5 (80)
	Samardzic et al., 2002[8]	12/14 (85.7)
	Blaauw and Sloff, 2003[9]*	22/25 (88.8)
	Stockinger et al., 2008[11]	6/7 (85.7)
	Sulaiman et al., 2009[12]	36/41 (87)
	Wellons et al., 2009[13]*	16/20 (80)
	Hems, 2011[14]	6/7 (85.7)
	Samardzic et al., 2011[15]	19/21 (90.5)
Axillary nerve as a recipient	Samardzic et al., 2002[8]	9/11 (81.8)
	Samardzic et al., 2011[15]	10/12 (83.3)
	Ray et al., 2012[16]	7/8 (87.5)

* obstetric brachial plexus palsy

TABLE 2 The results of thoracodorsal nerve transfer

	Series Reference number	Rate of useful recovery (%) (n/total n)
Musculocutaneous nerve as a recipient	Novak et al., 2002[18]*	5/6 (83.3)
	Samardzic et al., 2005[19]	12/12 (100)
	Samardzic et al., 2011[15]	13/13 (100)
Axillary nerve as a recipient	Samardzic et al., 2005[19]	14/15 (93.3)
	Haninec et al., 2007[20]	6/7 (85.7)
	Borrero, 2007[21]	8/8 (100)
	Sulaiman et al., 2009[12]	4/11 (36)
	Samardzic et al., 2011[15]	15/16 (93.7)
	Janes et al., 2022[22]**	6/8 (75)

*modified technique using two branches of the thoracodorsal nerve
**modified technique using two branches of the thoracodorsal and radial nerve branch to the medial head of the triceps

abduction, the reported total rates of recovery ranged between 81.8% and 87.5% for MPN and between 75% and 100% for TDN[19–22] with one exception: a 36% total rate of recovery reported by Sulaiman et al[12].

High-quality recovery was considered selectively, as it appeared in only a few series. In the restoration of elbow flexion, this was obtained in 50–83.4% of cases for MPN[8,11,14,15], and in 83.3–92.3% of cases for TDN[15,18,19]. In the restoration of shoulder abduction, high-quality recovery was obtained in 70–85.7% of cases for MPN[15,16], and in 60–75% of cases for TDN[15,22]. Some range of external arm rotation from the chest was obtained in 64.7% of cases for both nerves. A range of at least 90 degrees was obtained in 70% of cases for MPN and 60% of cases for TDN[15].

In 18 cases that used supplementation with an additional donor nerve (spinal accessory, upper intercostals and rarely the long thoracic or lower subscapular nerve), the obtained rates of total and high-quality recovery were somewhat higher. In the restoration of elbow flexion, these rates were 75% and 100% for MPN, and 100% for both locations for TDN. In the restoration of shoulder abduction, both total and high-quality recovery reached 100% for MPN, and 83.3% and 80% for TDN, which was the only exception in the obtained results[15].

Using the previously mentioned tests, comparative statistical analyses for all types of these nerve transfers were possible in a limited number of series[8,15,19]. There was no significant statistical difference in the results obtained using MPN or TDN as donors, either for MCN or AXN. The same was true for various techniques; solitary or combined nerve transfer. However, there could be a slight trend toward better results for TDN transfers. Additionally, based on the recovery percentages, there was a trend toward better quality of recovery for MPN to AXN and TDN to MCN transfers. In the procedure using TDN as a donor, useful functional recovery was significantly more frequent in cases of MCN reinnervation, compared to AXN (Chi-square test, $P = 0.04$). There was no statistically significant difference in the occurrence of useful functional recovery between MCN and AXN when using MPN as a donor.

Discussion

Indications for motor nerve transfers and the patient population that may benefit from such operations continue to expand, especially in the group of infraclavicular intraplexal transfers. The first indications were directly irreparable traction injuries of the brachial plexus with cervical spinal root avulsions or high intraforaminal spinal nerve injuries[23]. Later, the indications were significantly extended[24-26] including (a) extensive longitudinal nerve defects or neuromas in continuity, (b) injuries to one or several nerve elements at different levels, (c) associated vascular injuries, significant bone fractures and scarring at the site of injury, (d) surgery delayed for more than 12 months post-injury and/or unsuccessful previous direct nerve repair, and (e) elderly patients. Contraindications for nerve transfer are rare and include the presence of a better reconstructive procedure, excessive surgical delay (more than 12 months post-injury) and muscle strength in the donor innervation zone less than MRC grade 4.

The ideal timing for nerve transfer has not yet been established. However, it is widely accepted that surgery should be done in a period between 3 and 5 months after injury if there are neither clinical nor electromyographic signs of recovery[23,24,25]. The target muscle should be reinnervated between 12 and 18 months after injury in order to prevent muscle atrophy and loss of motor end plates. The presence of fibrillation potentials after this period is an indication that the denervated muscle is still viable. Regardless, some authors do not recommend surgery after a post-injury period of 9 months, with possible exceptions for infraclavicular intraplexal nerve transfers including MPN and TDN as donors in the restoration of upper arm functions.

Infraclavicular intraplexal nerve transfers (fascicular, medial pectoral, thoracodorsal and triceps branches) have several advantages over classical intraplexal and extraplexal transfers[24-26], including (1) the possibility for direct nerve anastomosis, (2) anastomosis closer to the target muscle, (3) a shorter distance and time span for nerve regeneration with earlier reinnervation, (4) surgery outside the zone of injury and scarred bed, (5) a faster recovery of higher quality, and (6) surgical procedures that are more technically straightforward and can be performed with a significant gain in operative time.

Functional priorities and recipient nerves

The restoration of strong and full-range elbow flexion, shoulder stability, and some range of arm abduction and external rotation is the main priority in repairing brachial plexus injuries with partial or total palsy[23,25,27,28]. The recovery of all of these movements is important for more physiological function, and in cases of upper brachial plexus palsy presents a completely functional arm[28]. The recovery of elbow flexion could be obtained by a reinnervation of MCN or sometimes by a separate reinnervation of its branches to the biceps and brachialis muscle[10]. MCN contains 3,069–7,911 myelinated fibers[29]. The average number of fibers in motor branches is 1,840 for the biceps and 1,826 for the brachialis muscle[30].

The recovery of complex shoulder function may be obtained using several strategies that could be the subject of some controversies. Some authors reported good results in the restoration of both shoulder functions reinnervating the suprascapular nerve, i.e. its target muscles: the supraspinatus and the infraspinatus[31,32]. Contrary to this, other authors stated that the supraspinatus muscle is only important for the initiation of shoulder abduction and external rotation, and that the reinnervation of this muscle does not result in acceptable recovery levels[33-35]. According to these statements, we used isolated reinnervation of AXN[8,15,19]. Aside from good arm abduction, we obtained a certain range of external rotation through the reinnervation of the teres minor muscle and the posterior part of the deltoid muscle. Additionally, the reinnervated long head of the biceps muscle also contributes to shoulder stability and to part of the range of its external rotation[36]. The final argument for an isolated reinnervation of AXN is the fact that the first muscle attracts the majority of regenerating axons. Therefore, transfer to the suprascapular nerve with a reinnervation of the supraspinatus muscle diminishes axonal sprout toward the infraspinatus muscle as the main external arm rotator[23]. Possibly, dual nerve transfer to both the suprascapular nerve and the anterior division of AXN could be the best option[26,37,38].

AXN contains between 4,967 and 8,437 myelinated fibers, with an average of 7,877 and 80% of those being motor fibers[29]. The number of motor fibers in the anterior division of AXN ranges from 2,700 to 4,052[39,40].

Donor nerves

Generally, there is no ideal donor nerve. Nevertheless, there are several important criteria for the choice of donor nerve[24-26]: (1) expendable nerves or nerves with a duplicated function, (2) close proximity to the recipient nerve facilitating a direct anastomosis, (3) close proximity to the target muscle and its end plates to decrease the regeneration distance, (4) pure motor fiber composition, possibly with a few sensory fibers, (5) large quantity of motor fibers, (6) donor-recipient axon count ratio 0.7 or higher — but a lower ratio should not always be a problem because only 20–30% of motor fibers are sufficient for the reinnervation of muscles with a simple function, such as the biceps muscle[30], (7) maximal nerve diameter matching enables more accurate coaptation, (8) MRC grade of at least M4 in the donor innervation zone, and (9) synergistic function with the recipient nerve offers more effective and faster cortical reintegration.

Both MPN and TDN are possible donors in cases with upper or extended upper brachial plexus palsy owing to their origin from the preserved brachial plexus elements. MPN receives nerve fibers from the C8 and T1 spinal nerves via the anterior division of the inferior brachial plexus trunk. Usually, the nerve ends in the sternal part of the pectoralis major muscle with several nerve branches[42]. There are usually two pectoral nerves – the lateral and medial pectoral nerve – connected with the pectoral arcade, which is formed predominantly by the first of the two[8,9]. Some authors even described three pectoral nerves[43]. MPN terminates in the pectoral muscle with two or three branches[44], at times even with four branches and sometimes with one or two branches from the pectoral arcade[8]. The branches from the arcade could be functional owing to the origin of the lateral pectoral nerve from the C5 to C7 spinal nerves with almost 50% of the approximately 1,000 fibers originating from the C7 nerve[45,46]. TDN receives motor fibers from the C7 and C8, and in some cases from the C6 spinal nerve via the posterior cord of the brachial plexus, and terminates with two branches in the latissimus dorsi muscle. Approximately 52% of TDN fibers originate from the C7 spinal nerve[47]. According to their characteristics (Table 3), MPN[23,44,46] and TDN[19,46,48,49] could be valuable donors in patients with upper or extended upper brachial plexus palsy. This is especially true for TDN, except in patients with extended upper palsy who might not have the necessary grade M4 strength in the latissimus

TABLE 3 Donor nerve characteristics

Donor nerve Reference number	Nerve diameter (in mm)	Number of fibers	Available length in mm
Medical pectoral[44,46]	15–27	1,170–2,140	30–78
Terminal branch[23]		400–600	
Arcade branch[23,46]		330–440	
Thoracodorsal nerve[19,46,48,49]	21–30	1,530–3,496	89–190 (123)
Lateral branch[49]			60–123 (81)

Parentheses = average values

dorsi muscle. Moreover, in this transfer there is no need for the proposed improvements, such as the exclusion of the lateral antebrachial cutaneous nerve[10,18] or the additional transfer to the brachialis branch of MCN as a supplement in the transfer of TDN to the biceps branch[10].

Problems and solutions

There are several potential problems in transfers of MPN and TDN for the restoration of upper arm function including: (1) a pre-existing donor nerve injury that may be a contraindication for nerve transfer, (2) donor nerve morbidity, (3) the need for cortical re-education, (4) possible co-contractions and (5) muscle loss for musculotendinous transfer. Additionally, in the transfer of MPN to both recipients and especially to MCN, potential problems include a large discrepancy in the diameter of the nerves and an insufficient length of MPN for direct anastomosis.

Another potential problem in these types of nerve transfers is the degree of pre-existing donor nerve injury, which may result in variations in the obtained results. There is always some damage to the nerves that are functional, but located on the “edge” of the lesion. Notably, muscle weakness becomes apparent when 50% of the motor fibers are lost. Fibrillation potentials detected on electromyography indicate potential injury and should be considered in the selection of the donor nerve[14].

Donor nerve morbidity is an important drawback, especially in cases with suboptimal (grade M3 or M4) function of the synergistic muscles. The potential functional loss could be avoided or diminished in several ways, depending on the donor nerve. It should be emphasized that the potential benefits of MPN and TDN nerve transfers should exceed the otherwise low rate of significant donor nerve morbidity based on several facts. When using MPN as a donor, the function of the pectoralis major muscle could be partially preserved owing to its complex innervation pattern that includes both pectoral nerves, especially the lateral pectoral nerve, with significant contributions from nerve fibers from the C7 spinal nerve. Similarly, in rare cases, this may be the reason for a partial functional preservation of the synergistic teres major muscle. Certainly, this is not the case in extended upper brachial plexus palsy. Some surgical strategies may also be important in diminishing MPN morbidity following its section. One of the most important procedures is the preservation of some of the MPN terminal branches[8,44,45], since even one preserved branch could produce strong contractions of the pectoralis major muscle[14,44]. Another, though rarely reported, possibility is end-to-side anastomosis between MCN and MPN[13,50]. Significant functional loss from the TDN section was not registered, as reported by several authors[10,14,18,21,22]. This is especially important in cases with a simultaneous use of both donors in nerve transfer, because of the synergistic function of both nerves.

Function after nerve transfer is dependent on the donor nerve to some extent, and there is a need for cortical re-education. Synergistic muscle function between the donor and recipient requires less postoperative re-education based on pre-existing cortical and medullary interconnections. Some antagonistic functions, such as that of the deltoid muscle following MPN or TDN transfer, could be successfully retrained in a relatively short period of time due to a closer functional relationship and cerebral cortical representation.

Possible co-contractions could be very disabling, such as in intraplexal nerve transfers using spinal nerve stumps as donors, because of the massive cross-innervation of the synergistic and antagonistic muscles[23]. On the other hand, in the MPN to MCN transfer, contractions of the biceps muscle associated with arm adduction may be useful[14]. Moreover, some authors favor this transfer in relation to fascicular transfers[14].

According to the reported nerve dimensions, the cross-sectional area of MPN usually covers 60–70% of the same area of the recipient nerves[51,52]. The problem of diameter mismatch between MPN and MCN could be solved by using several methods, including an epineurectomy of the recipient nerve with epiperineurial suture to the donor nerve, anastomosis with a part of MCN or its fascicular group, and bundling of several terminal branches, sometimes using the sectioned pectoral arcade as well[8]. In cases of a failure of these procedures, another option is a combined nerve transfer using an additional second donor nerve. Nerves used as a supplement in nerve transfer could be extraplexal, spinal accessory or, more frequently, upper intercostals[8,15,19] or intraplexal nerves, such as grafting the anterior division of the lateral cord to the medial part of MCN[12]. Similarly, a combined transfer was used in the reinnervation of the AXN anterior division using TDN and the medial triceps muscle branch with the intention to increase the number of regenerating axons[22]. Although controversial, these combined nerve transfers increase the number of nerve fibers that cross distal nerve anastomosis at the site with anatomically and physiologically distinct fascicles of the recipient nerve[5]. Regarding the previous options, it seems that the most acceptable one could be the anastomosis of MPN with the MCN biceps branch without additional nerve transfer to the brachialis branch.

The length of TDN is sufficient for a direct distal anastomosis with both recipients. The length of MPN is sufficient for a direct anastomosis to AXN in all cases, and in about two thirds of cases for transfers to MCN. In the remaining one third of cases, there is a nerve gap of less than 50 mm, usually 15–20 mm in length, that should be grafted[44]. There are several methods used to avoid or at least diminish the length of the nerve gap. These include retrograde neurolysis of MCN into the lateral cord, distal dissection of the MPN terminal branches and the previously mentioned section of the pectoral arcade[8,45]. These methods could be used simultaneously if necessary.

Muscle from the donor innervation zone is lost for musculotendinous transfer, which is especially important for the latissimus dorsi muscle transfer. Therefore, a balance of potential risks and benefits should be carefully estimated for each individual case.

Conclusion

Based on this review, we were able to make several conclusions with practical implications. Generally, as in other types of nerve transfers, patient selection is crucial, especially in terms of their age and the timing of surgery. According to our experience and published results in the literature, the reinnervation of the musculocutaneous and axillary nerve using collateral branches of the brachial plexus have several advantages; (1) the potential benefits significantly exceed a relatively low rate of donor nerve morbidity, (2) simultaneous reinnervation of both recipients is possible in one stage and through the same surgical approach, (3) the decision on the combination of donors and recipients in cases of simultaneous reinnervation of both nerves is based on the anatomical relationship between nerves regarding the possibility for direct coaptation, (4) such transfers result in a high-grade functional recovery in the majority of cases, independent of the donor-recipient nerve combination, (5) recovered functions are similar to those of the original muscles, (6) the obtained results are at least similar to those of the other infraclavicular transfers, and finally, (7) the transfer of brachial plexus collateral nerve branches is an acceptable option when some of the infraclavicular transfers are not possible because of extensive two-level lesions that include more distal nerve injury. According to the abovementioned statements, MPN and TDN transfers are reliable options and should not be considered as a second-line procedure.

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SAŽETAK

Transfer medijalnog pektoralnog i torakodorzalnog živca u slučajevima gornje paralize brahijalnog pleksusa: kontroverze, problemi i rješenja

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Dva osnovna prioriteta u uspostavljanju funkcije ruke poslije ozljeda brahijalnog pleksusa, bez obzira na njihovu ekstenziju, su uspostavljanje fleksije u laktu i funkcije ramena. U slučajevima ozljeda kod kojih je nemoguće izvršiti izravnu rekonstrukciju živaca, tzv. transfer živaca, odnosno spajanje zdravih, funkcionalno manje značajnih živaca s oštećenim živcima jedina je mogućnost za uspostavljanje funkcija. U ovim operacijama primjenjivani su brojni ekstra i intrapleksusni donorski živci. Srećom, u slučajevima gornje paralize brahijalnog pleksusa, koja je posljedica oštećenja spinalnih živaca C5, C6 i u nekim slučajevima C7, postoji širi izbor donorskih živaca koji uključuje intrapleksusne bočne grane, fascikuluse ulnarisa i medijanusa te mišićne grane radijalisa za triceps. Naša se iskustva uglavnom temelje na primjeni bočnih grana brahijalnog pleksusa, odnosno medijalnog pektoralnog i torakodorzalnog živca. Ciljevi ovog preglednog rada, pored procjene objavljenih rezultata, su analiza kontroverznih stavova, izvjesnih proturječnih tehničkih problema i njihova nadilaženja. Glavni je zaključak da ovi transferi mogu biti pouzdana metoda u kirurškom liječenju gornje paralize ruke, bilo da se koriste samostalno ili u kombinaciji s drugim metodama transfera živaca.

KLJUČNE RIJEČI

Brahijalni pleksus; *Donorski živci*; *N. pectoralis medialis*; *Transfer živaca*; *N. Thoracodorsalis*