Early Functional Recovery of Elbow Flexion and Supination Following Median and/or Ulnar Nerve Fascicle Transfer in Upper Neonatal Brachial Plexus Palsy

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Background: Nerve transfers using ulnar and/or median nerve fascicles to restore elbow flexion have been widely used following traumatic brachial plexus injury, but their utility following neonatal brachial plexus palsy remains unclear. The present multicenter study tested the hypothesis that these transfers can restore elbow flexion and supination in infants with neonatal brachial plexus palsy.

Methods: We retrospectively reviewed the cases of thirty-one patients at three institutions who had undergone ulnar and/or median nerve fascicle transfer to the biceps and/or brachialis branches of the musculocutaneous nerve after neonatal brachial plexus palsy. The primary outcome measures were postoperative elbow flexion and supination as measured with the Active Movement Scale (AMS). Patients were followed for at least eighteen months postoperatively unless they obtained full elbow flexion or supination (AMS = 7) prior to eighteen months of follow-up.

Results: Twenty-seven (87%) of the thirty-one patients obtained functional elbow flexion (AMS ≥ 6), and twenty-four (77%) obtained full recovery of elbow flexion against gravity (AMS = 7). Of the twenty-four patients for whom recovery of supination was recorded, five (21%) obtained functional recovery. Combined ulnar and median nerve fascicle transfers were performed in five patients and resulted in full recovery of elbow flexion against gravity and supination of AMS ≥ 5 for all five. Single-fascicle transfer was performed in twenty-six patients and resulted in functional flexion in 85% (twenty-two of twenty-six) and functional supination in 15% (three of twenty). Patients with nerve root avulsion were treated at a younger age ($p < 0.01$), had poorer preoperative elbow flexion ($p < 0.01$), and recovered greater supination ($p < 0.01$) compared with patients with dissociative recovery. Younger patients ($p < 0.01$) and patients with C5-C6 avulsion ($p < 0.02$) recovered the greatest supination. One patient sustained a transient anterior interosseous nerve palsy after median nerve fascicle transfer.

Conclusions: Ulnar and/or median nerve fascicle transfers were able to effectively restore functional elbow flexion in patients with nerve root avulsion, dissociative recovery, or late presentation following neonatal brachial plexus palsy. Recovery of supination was less, with greater success noted in younger patients with nerve root avulsion.

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

Peer Review: This article was reviewed by the Editor-in-Chief and one Deputy Editor, and it underwent blinded review by two or more outside experts. It was also reviewed by an expert in methodology and statistics. The Deputy Editor reviewed each revision of the article, and it underwent a final review by the Editor-in-Chief prior to publication. Final corrections and clarifications occurred during one or more exchanges between the author(s) and copyeditors.

Return of elbow flexion has been used as a sentinel event for recovery of motor function in children with neonatal brachial plexus palsy[1]. In children who do not recover upper extremity function, microsurgical brachial plexus exploration and subsequent nerve grafting and/or nerve transfers are performed. When intact upper trunk nerve roots

Disclosure: None of the authors received payments or services, either directly or indirectly (i.e., via his or her institution), from a third party in support of any aspect of this work. One or more of the authors, or his or her institution, has had a financial relationship, in the thirty-six months prior to submission of this work, with an entity in the biomedical arena that could be perceived to influence or have the potential to influence what is written in this work. No author has had any other relationships, or has engaged in any other activities, that could be perceived to influence or have the potential to influence what is written in this work. The complete **Disclosures of Potential Conflicts of Interest** submitted by authors are always provided with the online version of the article.

TABLE I Demographic and Injury Characteristics of Patients with Median and/or Ulnar Nerve Fascicle Transfer for Upper Neonatal Brachial Plexus Palsy

	All Patients	Single Nerve Transfer	Double Nerve Transfer	P Value
Institution				0.016
Cincinnati	13 (42%)	8 (31%)	5 (100%)	
Philadelphia	14 (45%)	14 (54%)	—	
Barcelona	4 (13%)	4 (15%)	—	
Sex				1.00
Male	18 (58%)	15 (58%)	3 (60%)	
Female	13 (42%)	11 (42%)	2 (40%)	
Laterality				0.56
Right	24 (77%)	19 (73%)	5 (100%)	
Left	7 (23%)	7 (27%)	—	
Donor nerve				—
Ulnar	23 (74%)	23 (88%)	—	
Median	3 (10%)	3 (12%)	—	
Ulnar and median	5 (16%)	—	5 (100%)	
Recipient nerve				—
Biceps	26 (84%)	26 (100%)	—	
Biceps and brachialis	5 (16%)	—	5 (100%)	
Neurologic level				0.34
C5-C6	17 (55%)	13 (50%)	4 (80%)	
C5-C7	14 (45%)	13 (50%)	1 (20%)	
Surgical indication				0.042
Avulsion	10 (32%)	6 (23%)	4 (80%)	
Dissociative recovery	16 (52%)	15 (58%)	1 (20%)	
Late presentation	3 (10%)	3 (12%)	—	
Failed nerve grafting	2 (6%)	2 (8%)	—	
Age at surgery *(mo)*				0.054
Mean and std. dev.	8.4 ± 4.7	9.1 ± 4.8	5.0 ± 1.9	
Median (IQR*)	7 (5-12)	7 (6-13)	4 (4-7)	
Range	3-20	3-20	3-7	
Follow-up *(mo)*				0.23
Mean and std. dev.	35.1 ± 19.1	34.4 ± 20.5	38.8 ± 10.6	
Median (IQR*)	28 (21-47)	27 (21-44)	43 (28-48)	
Range	6-81	6-81	26-49	

*IQR = interquartile range.

are identified during brachial plexus exploration, sural nerve grafting is the procedure of choice. However, in the presence of avulsed nerve roots, nerve transfers are performed to augment upper trunk function[2]. In patients who present after one year of age, primary nerve transfer surgery has been proposed to decrease the time that a muscle is denervated[2,3]. An additional indication for nerve transfer surgery is development of dissociative recovery, in which upper trunk function involving the shoulder recovers but elbow flexion does not[3].

The use of ulnar nerve fascicles as the donor for a nerve transfer to restore elbow flexion was first described by Oberlin et al. in 1994[4]. Augmentation of this transfer to include nerve transfer to the brachialis muscle to increase elbow flexion torque was described in 2003[5], at approximately the same time that median nerve fascicle transfer was first proposed[6,7]. Combined transfers of the median and ulnar nerve fascicles to the brachialis and biceps were described in 2004 and 2005[8,9]. Although these transfers have been used and studied extensively in adults with traumatic brachial plexus palsy, there are limited data on the efficacy of these transfers for restoring elbow flexion in children, with only ten cases previously reported[2,10,11]. Additionally, the brachialis is a primary elbow flexor, whereas the biceps is a primary forearm supinator and secondary elbow flexor[3,12]. Thus, a combined nerve transfer to both the biceps and brachialis should increase elbow flexion torque and possibly provide independent muscular control of supination[9]. We report on thirty-one patients who underwent selective nerve transfers from the ulnar and/or median nerves to the biceps and/or brachialis muscles and discuss the indications, recovery of elbow flexion and supination, and complications in this cohort.

Materials and Methods

After obtaining authorization from each institutional review board, we reviewed the records of patients who had loss of elbow flexion due to brachial plexus birth palsy involving the upper trunk (C5-C6 or C5-C7) and were treated with nerve transfer by five surgeons at three institutions. Patients were excluded if they had concomitant nerve grafting to the upper trunk but were included if additional isolated nerve transfers were performed to improve shoulder function. Thirty-one patients met the inclusion criteria of a minimum of eighteen months of follow-up after surgery or achievement of a score of 7/7 according to the Active Movement Scale[13] (AMS) for the motion being tested (whichever was reached first). The patient demographic information, donor nerve, recipient nerve, type of injury (upper trunk [C5-C6] or extended upper trunk [C5-C7]), age at surgery, and previous or concomitant surgical procedures (if any) were recorded (Table I). AMS scores were obtained by a certified hand therapist and/or the treating physician at each clinical encounter. AMS scores were selected for this multicenter study because they demonstrate the best intraobserver reliability of all functional outcome measures in children with neonatal brachial plexus palsy[13]. Functional recovery of elbow flexion and supination was defined as an AMS score of ≥6 as standardized by Clarke et al.[14].

The indication for surgery was failure to recover elbow flexion, as indicated by an AMS of ≤3, because of (1) late presentation, defined as presentation after twelve months of age (n = 3); (2) dissociative recovery, defined as shoulder abduction of >90° or an AMS of ≥6 (n = 16)[3]; (3) nerve root avulsion seen at the time of microsurgical reconstruction (n = 10); or (4) incomplete recovery after microsurgical nerve grafting (n = 2; one patient had an AMS of 1 after 14.5 months and one had an AMS of 0 after 15.5 months)[2,3]. Additionally, the family of one child opted for primary nerve transfers at nine months of age instead of exploration and nerve grafting for poor C5-C6 recovery after an initial C5-C7 injury. The surgical technique has been previously described in detail[3]. Depending on surgeon preference, the median and/or the ulnar nerve were used as donors as both donor fascicles have been used successfully to regain elbow flexion function, with neither having been proven superior[4-11].

Statistical Analysis

Nonparametric statistical tests were used because of the small sample size and the non-normal distribution of the AMS elbow flexion and supination scores. Mann-Whitney tests were used to compare age and preoperative and postoperative elbow flexion and supination scores according to neurologic level and according to surgical indication. Kruskal-Wallis tests were used to compare postoperative elbow flexion and supination among groups defined by combinations of the neurologic level and the surgical indication. Spearman correlations were used to determine the association between age at surgery and postoperative elbow flexion and supination. Transfer types were not compared statistically because of the small number of double nerve transfers and the substantial heterogeneity between the groups (Table I). A p value of <0.05 was considered significant.

Source of Funding

No external funding was obtained for this study.

Results

Concomitant surgical procedures were performed in twenty-three of thirty-one patients at the time of the nerve transfer performed to restore elbow flexion. These procedures included transfer of the spinal accessory nerve to the suprascapular nerve (n = 17), transfer of the radial nerve branch innervating the long head of the triceps to the axillary nerve (n = 8), release of a shoulder internal rotation contracture (n = 2), and/or latissimus dorsi and teres major tendon transfers to the posterior aspect of the rotator cuff (n = 3). The mean age at surgery was 8.4 months (range, three to twenty months), and the mean duration of follow-up was thirty-five months (range, six to eighty-one months). The analysis of elbow flexion included two patients who had obtained full recovery of elbow flexion against gravity (AMS = 7) at six months postoperatively. However, as neither of these patients had obtained full recovery of supination against gravity at that time and they did not return to the clinic for further follow-up, these two patients were excluded from the supination analysis. An additional five patients were excluded from the supination analysis because of missing follow-up supination data.

TABLE II Functional Recovery of Elbow Flexion and Supination*

	All Patients	Single Nerve Transfer	Double Nerve Transfer
Flexion			
Initial	1 (0-2)	1 (0-2)	0 (0-0)
Follow-up	7 (7-7)	7 (6-7)	7 (7-7)
Change	6 (5-7)	6 (4-6)	7 (7-7)
Supination			
Initial	0 (0-0)	0 (0-0)	0 (0-0)
Follow-up	3 (2-5)	3 (2-5)	6 (5-7)
Change	3 (2-5)	3 (2-5)	6 (5-7)

*The values are given as the median AMS score, with the interquartile range in parentheses.

The median preoperative AMS score for elbow flexion was 1 (range, 0 to 3). The preoperative AMS score for supination was 1 in one patient and 0 in all other patients. Twenty-seven (87%) of the thirty-one patients obtained functional elbow flexion (AMS ≥ 6) after surgery, with twenty-four (77%) obtaining full recovery of flexion against gravity. Five (21%) of twenty-four patients obtained functional supination (AMS ≥ 6), with two (8%) obtaining full recovery of supination against gravity.

Combined ulnar and median nerve fascicle transfers were performed in five patients, all of whom were seven months of age or younger (median, four months) and had preoperative AMS scores of 0 for both elbow flexion and supination (Table II). Four of these patients had nerve root avulsion (three at C5-C6, one at C5-C7), and the fifth had dissociative recovery. All of these patients obtained full recovery of elbow flexion against gravity, and the median AMS score for supination was 6 (range, 5 to 7).

Single nerve fascicle transfers were performed in the remaining twenty-six patients and resulted in functional flexion (AMS ≥ 6) in 85% (twenty-two of twenty-six) and functional supination (AMS ≥ 6) in 15% (three of twenty) (Table II). Six of these patients had nerve root avulsion, which resulted in a preoperative AMS score of 0 for elbow flexion, and were treated with ulnar nerve transfer at a median age of five months (range, three to seven months).

In the combined transfer subgroup, the four patients with C5-C6 avulsion all obtained full recovery of elbow flexion against

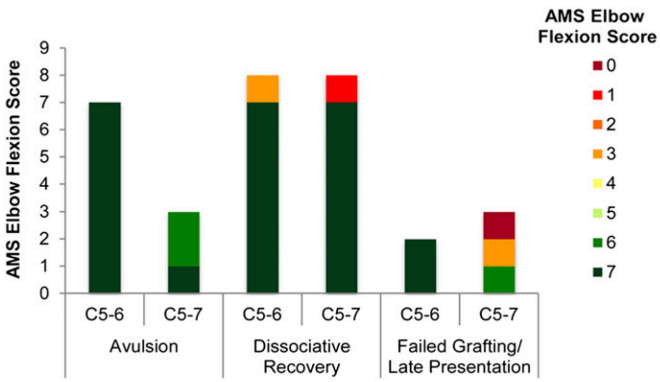

Fig. 1-A

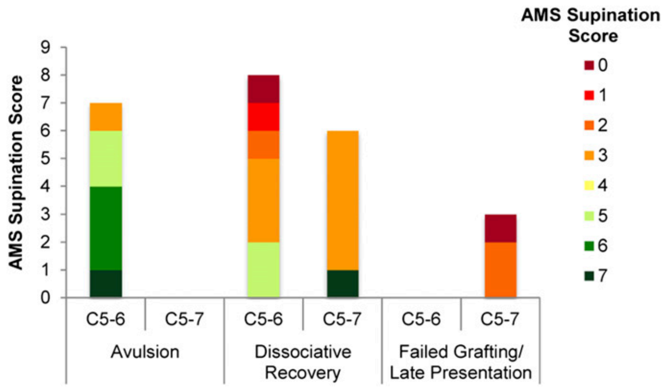

Fig. 1-B

Stacked bar graphs showing the effect of nerve fascicle transfers on recovery of elbow flexion (**Fig. 1-A**) and supination (**Fig. 1-B**).

gravity, and the median AMS score for supination was 6 (range, 3 to 7). The two patients with C5-C7 avulsion both recovered functional elbow flexion (AMS ≥ 6); no supination data were available.

In the single nerve transfer group, the fifteen patients with dissociative recovery had a median age of seven months (range, five to fifteen months), and their median preoperative AMS score for elbow flexion score was 2 (range, 0 to 3). Six of the seven patients with dissociative recovery and a C5-C6 injury obtained full recovery of elbow flexion against gravity, but none recovered functional supination (median AMS score, 3; range, 0 to 5). Seven of the eight patients with dissociative recovery and a C5-C7 injury obtained full recovery of elbow flexion against gravity, but only one obtained full recovery of supination against gravity (median AMS score, 3; range, 3 to 7).

Three patients presented late, at a median age of fifteen months (range, thirteen to seventeen months); the preoperative AMS score for elbow flexion was 0 in one patient and 2 in the other two. All three of these patients were treated with ulnar nerve fascicle transfer. Both patients with a C5-C6 injury obtained full recovery of elbow flexion against gravity and obtained an AMS score of 3 for supination, and the patient with a C5-C7 injury obtained AMS scores of 3 for elbow flexion and 2 for supination.

Two patients with a C5-C7 injury had previously undergone nerve grafting, which failed to restore elbow flexion, at 3.5 and 4.9 months of age, and these patients also underwent late ulnar nerve transfer. The former patient, who had a preoperative AMS score of 1 for elbow flexion, recovered functional elbow flexion (AMS = 6) and obtained an AMS score of 2 for supination after ulnar nerve transfer at eighteen months of age. The latter patient, who had a preoperative AMS score of 0 for elbow flexion, did not recover any flexion or supination after ulnar nerve transfer at 20.5 months of age.

Because of the selection criteria utilized, patients with nerve root avulsion were treated at a significantly younger age (chi-square = 19, $p < 0.01$) and had a significantly poorer preoperative AMS score for elbow flexion (chi-square = 14, $p < 0.01$) compared with patients with dissociative recovery or late treatment due to failed grafting or late presentation. Postoperative elbow flexion scores did not differ between patients with avulsion and those with dissociative recovery, even when the level of injury was taken into account (chi-square = 6, $p = 0.11$) (Fig. 1-A). Patients with nerve root avulsion recovered greater supination following nerve transfer compared with patients with dissociative recovery or late treatment due to failed grafting or late presentation (chi-square = 12, $p < 0.01$). More

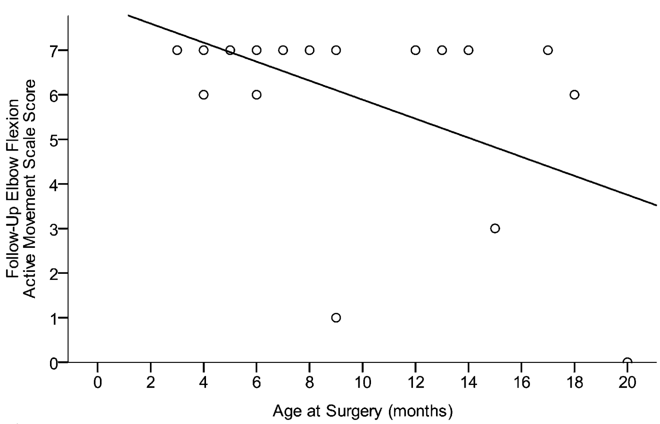

Fig. 2-A

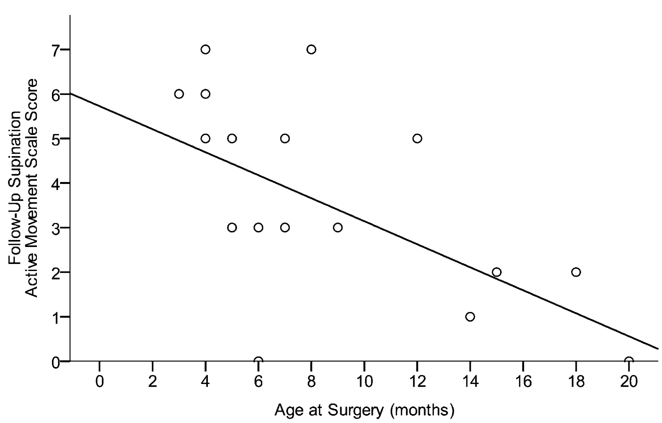

Fig. 2-B

Scatter plots showing the regression line for the effect of age at the time of surgery on the postoperative AMS scores for elbow flexion (**Fig. 2-A**) and supination (**Fig. 2-B**). Some points are superimposed.

TABLE III Literature on Nerve Transfer for Recovery of Elbow Flexion in Neonatal Brachial Plexus Palsy*

Donor Nerve	Study	No. of Transfers	AMS ≥ 6	Advantages	Disadvantages
Ulnar fascicle				Coaptation near MEP. Lower trunk innervation. Innervation redundancy	Not available for global palsy
	Noaman et al.[2]	7	71%†		
	Al-Qattan[10]	2	100%		
	Shigematsu et al.[11]	1	100%		
Intercostal nerve				Available for global palsy	Contraindicated for phrenic nerve palsy. Risk for ''breathing arm.'' Coaptation far from MEP
	El-Gammal et al.[17]	31	94%		
	Kawabata et al.[16]	31	84%		
	Luo et al.[18]	24	71%†		
Medial pectoral nerve				Lower trunk innervation. Innervation redundancy. Minimal loss of function	Not available for global palsy. Coaptation far from MEP
	Blaauw and Slooff[19]	25	68%		
	Wellons et al.[20]	20	80%		
Spinal accessory nerve				Available for global palsy	Interpositional nerve grafting. Coaptation far from MEP
	Kawabata et al.[21]	1	100%†		
Hypoglossal nerve				Available for global palsy	Interpositional nerve grafting. Loss of tongue function for feeding and speaking. Coaptation far from MEP
	Blaauw et al.[22]	6	66%‡		

*MEP = motor end plate. †Results were reported as the MRC score; the values indicate patients with a score of 4/5 or 5/5. ‡Results were reported as the Mallet score and strength of contraction; the values indicate patients with ''powerful'' contraction.

specifically, patients with C5-C6 avulsion recovered greater supination compared with patients with C5-C7 dissociative recovery, and patients with C5-C6 dissociative recovery recovered the least supination (chi-square = 8, $p < 0.02$) (Fig. 1-B). Younger age at the time of the nerve transfer was correlated with greater elbow flexion ($r = -0.40$, $p < 0.03$) (Fig. 2-A) and greater supination ($r = -0.64$, $p < 0.01$) (Fig. 2-B) at the time of follow-up. Indeed, no patient who was more than eight months of age at the time of surgery obtained full recovery of supination against gravity, whereas the oldest patient to recover full elbow flexion was seventeen months of age at the time of surgery. Although the double nerve transfers were performed by two different surgeons at one of the institutions, postoperative elbow flexion and supination in the whole cohort did not differ according to institution or surgeon ($p > 0.05$). One patient had a transient anterior interosseous nerve palsy after median nerve fascicle transfer; no motor nerve deficits occurred after ulnar nerve fascicle transfer.

Discussion

Various nerve transfers for restoring elbow flexion in children with neonatal brachial plexus palsy have been described. The transfers have involved intercostal nerves[15-18], fascicles of the median and ulnar nerves[2,10,11], pectoral nerves[19,20], the spinal accessory nerve[21], and the hypoglossal nerve[22] (Table III). The indications for nerve transfer surgery in patients with neonatal brachial plexus palsy typically include an inability to undergo standard nerve grafting because nerve root avulsion is identified at the time of brachial plexus exploration. More recently, these indications have been expanded to include patients with dissociative shoulder recovery[2,3], those in whom neuroma excision and grafting would eliminate previously noted recovery, those in whom previous nerve surgery has been unsuccessful[2,3,10], and those who present after one year of age when exploration and grafting might not improve the natural history of recovery[1-3,10].

In the present study, 87% of the thirty-one patients obtained functional elbow flexion, whereas only 21% obtained functional supination. The previously reported results of single nerve transfer for elbow flexion have been good regardless of which donor nerve is used, with an overall recovery rate of approximately 80% (Table III)[2,10,11,16-22]. The five patients treated with double nerve fascicle transfers in the present study obtained full recovery of elbow flexion against gravity and AMS scores of 5 to 7 for supination. All five of these patients were treated at less than eight months of age, and four had nerve root avulsion. The group treated with single nerve transfer was much more variable, containing fifteen patients with dissociative recovery. The latter patients were older than the patients with nerve root avulsion and had better preoperative elbow flexion; thirteen (87%) of the fifteen obtained functional elbow flexion against gravity.

Age at surgery was a significant predictor of postoperative outcome. The oldest child to obtain full recovery of elbow flexion against gravity was seventeen months old at the time of surgery, and the oldest child to recover functional elbow flexion was eighteen months old (Fig. 2-A). Recovery of functional supination was notably poorer than recovery of elbow flexion and did not occur in any patients treated after eight months of age (Fig. 2-B). We cannot use the data to establish a definitive age cutoff for these nerve transfers, but we advise prudent counseling when considering these procedures in children over eighteen months of age.

To our knowledge, the largest previously reported series involving ulnar nerve fascicle transfer to the biceps in patients with neonatal brachial plexus palsy included seven patients, and these patients presented late (at eleven to twenty-four months)[2]. Five patients in that series obtained recovery of elbow flexion against gravity, with the two failures occurring in patients who underwent surgery at nineteen and twenty-four months of age. No observable motor or sensory loss related to the donor site was observed as a result of the nerve transfer. Al-Qattan[10] reported on two patients with delayed presentation and stable shoulder function who were treated with ulnar nerve fascicle transfer at sixteen and eighteen months of age. Both patients obtained full elbow flexion after five months, with no ulnar nerve deficits noted. Shigematsu et al.[11] reported on one patient who underwent ulnar nerve fascicle transfer to the biceps as well as transfer of the spinal accessory nerve to the suprascapular nerve at eight months of age. The patient obtained full elbow flexion and 90° of shoulder abduction after five months. Combining these results, recovery of elbow flexion was seen in eight of ten patients, a rate similar to that in the present study.

Intercostal nerve transfers to the musculocutaneous nerve have been used in pediatric and adult patients with brachial plexus palsy. Kawabata et al. reported that 84% of thirty-one pediatric patients treated with intercostal nerve transfers at a mean age of 5.8 months obtained recovery of elbow flexion against gravity[16]. El-Gammal et al. reported good results in thirty-one patients (mean age, fourteen months) with neonatal brachial plexus palsy, with 94% obtaining at least elbow flexion against gravity[17]. Luo et al.[18] reported on twenty-four patients who underwent transfer of the intercostal nerve to the upper trunk or directly to the musculocutaneous nerve at an age of five months; 71% obtained recovery of M4 strength on the British Medical Research Council (MRC) scale.

Like the ulnar nerve, the medial pectoral nerve is derived almost exclusively from the lower trunk and is preserved in all but global palsies. Blaauw and Slooff[19] and Wellons et al.[20] reported on a total of forty-five patients with neonatal brachial plexus palsy who were treated with medial pectoral nerve transfer. Thirty-three of the forty-five patients regained functional elbow flexion against gravity, defined as the ability to bring the hand to the mouth, but it is unclear how many obtained full recovery of elbow flexion against gravity. The spinal accessory and hypoglossal nerves have also been used as donors[21,22], with success noted in a small number of patients.

We prefer to use fascicles of the median and/or ulnar nerves as donors for several reasons. (1) The donor and recipient nerves are adjacent, requiring only one operative field and dissection. (2) The coaptation can be made close to the motor end plate, allowing for earlier reinnervation. (3) Donor nerve deficits are avoided because of redundancies and crossover between fascicles in the median and ulnar nerves[4,23,24]. (4) Full ulnar nerve function is preserved in all cases of neonatal brachial plexus palsy involving only the upper and middle trunk. In patients without intact lower trunk function, we prefer the use of the intercostal nerve as a donor except in cases of phrenic nerve palsy, when intercostal nerve transfer is contraindicated[25].

Our study demonstrated that recovery of supination was poorer than recovery of elbow flexion, especially in older infants. We theorize that the reinnervation of both muscles will allow for independent use of the biceps for supination and the brachialis for elbow flexion, which could allow the biceps to be recruited to provide maximum elbow flexion torque. A single patient had transient motor palsy after median nerve fascicle transfer. Other authors have reported transient paresthesias in the median and ulnar nerve distributions after nerve fascicle transfer in adult patients[26], but to our knowledge no permanent complications have been noted. The assessment of transient paresthesias is impossible in the infant.

There are several limitations to this study. First, it involved the retrospective review of data collected at three separate institutions. All of these institutions have institutional review board-approved prospective collection of general data on patients with brachial plexus palsy, but differences in the assignment of postoperative AMS scores for elbow flexion and supination are possible. We chose the AMS scale as our primary functional outcome measure because this tool provides a standard scale with which to measure muscle function and it has the best reliability, especially across institutions[13]. Additionally, Curtis et al. demonstrated that the AMS scale has excellent interrater reliability for elbow flexion but only moderate interrater reliability for pronation-supination in infants and toddlers[27].

Second, although the surgical procedure and postoperative care have been well described, institutional variability is possible, especially in the selection of the donor nerve fascicle, as has been noted in our study. This tendency for selection bias is inherent in any such retrospective multicenter study, but our data analysis suggests that there were neither institutional nor surgeon differences in outcomes despite the institutional variability in surgical technique. In the absence of a consensus opinion regarding which donor fascicle performs best, the identification of the best choice for the nerve transfer was made intraoperatively on the basis of surgeon preference.

The study had insufficient power to permit a statistical comparison between single and double nerve fascicle transfers. Furthermore, the two transfer groups differed considerably in composition, with the double nerve fascicle transfer group consisting of young patients, most of whom had nerve root avulsion. Conclusions regarding the differences between single and double nerve fascicle transfers in adults have varied, with some authors reporting improved results with double transfers[28] and others reporting no difference[26].

In summary, we report on a large series of nerve transfers used to restore elbow flexion and supination in neonatal brachial plexus palsy. Our data suggest that elbow flexion against gravity can be obtained in most patients who have one of several different surgical indications, and that single and double nerve fascicle transfers may improve recovery of supination in young patients with C5-C6 nerve root avulsion. Older patients showed less recovery of supination following these transfers, with no patient over eight months of age recovering functional supination. We recommend nerve transfers for restoration of elbow flexion in patients with nerve root avulsion, dissociative recovery, or failed nerve grafting or late presentation. We also recommend nerve transfers for restoration of supination in patients with C5-C6 nerve root avulsion. ■

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References

1. Waters PM. Comparison of the natural history, the outcome of microsurgical repair, and the outcome of operative reconstruction in brachial plexus birth palsy. J Bone Joint Surg Am. 1999 May;81(5):649-59.

2. Noaman HH, Shiha AE, Bahm J. Oberlin's ulnar nerve transfer to the biceps motor nerve in obstetric brachial plexus palsy: indications, and good and bad results. Microsurgery. 2004;24(3):182-7.

3. Kozin SH. Nerve transfers in brachial plexus birth palsies: indications, techniques, and outcomes. Hand Clin. 2008 Nov;24(4):363-76: v.

4. Oberlin C, Béal D, Leechavengvongs S, Salon A, Dauge MC, Sarcy JJ. Nerve transfer to biceps muscle using a part of ulnar nerve for C5-C6 avulsion of the brachial plexus: anatomical study and report of four cases. J Hand Surg Am. 1994 Mar;19(2):232-7.

5. Tung TH, Novak CB, Mackinnon SE. Nerve transfers to the biceps and brachialis branches to improve elbow flexion strength after brachial plexus injuries. J Neurosurg. 2003 Feb;98(2):313-8.

6. Sungpet A, Suphachatwong C, Kawinwonggowit V. One-fascicle median nerve transfer to biceps muscle in C5 and C6 root avulsions of brachial plexus injury. Microsurgery. 2003;23(1):10-3.

7. Hou Z, Xu Z. Nerve transfer for treatment of brachial plexus injury: comparison study between the transfer of partial median and ulnar nerves and that of phrenic and spinal accessary nerves. Chin J Traumatol. 2002 Oct;5(5):263-6.

8. Tung TH, Weber RV, Mackinnon SE. Nerve transfers for the upper and lower extremities. Oper Tech Orthop. 2004 Jul;14(3):213-22.

9. Mackinnon SE, Novak CB, Myckatyn TM, Tung TH. Results of reinnervation of the biceps and brachialis muscles with a double fascicular transfer for elbow flexion. J Hand Surg Am. 2005 Sep;30(5):978-85.

10. Al-Qattan MM. Oberlin's ulnar nerve transfer to the biceps nerve in Erb's birth palsy. Plast Reconstr Surg. 2002 Jan;109(1):405-7.

11. Shigematsu K, Yajima H, Kobata Y, Kawamura K, Maegawa N, Takakura Y. Oberlin partial ulnar nerve transfer for restoration in obstetric brachial plexus palsy of a newborn: case report. J Brachial Plex Peripher Nerve Inj. 2006; 1:3. Epub 2006 Sep 29.

12. Bernstein AD, Breslow MJ, Jazrawi LM. Distal biceps tendon ruptures: a historical perspective and current concepts. Am J Orthop (Belle Mead NJ). 2001 Mar;30(3):193-200.

13. Bae DS, Waters PM, Zurakowski D. Reliability of three classification systems measuring active motion in brachial plexus birth palsy. J Bone Joint Surg Am. 2003 Sep;85(9):1733-8.

14. Clarke HM, Al-Qattan MM, Curtis CG, Zuker RM. Obstetrical brachial plexus palsy: results following neurolysis of conducting neuromas-in-continuity. Plast Reconstr Surg. 1996 Apr;97(5):974-82; discussion 983-4.

15. Nagano A, Ochiai N, Okinaga S. Restoration of elbow flexion in root lesions of brachial plexus injuries. J Hand Surg Am. 1992 Sep;17(5):815-21.

16. Kawabata H, Shibata T, Matsui Y, Yasui N. Use of intercostal nerves for neurotization of the musculocutaneous nerve in infants with birth-related brachial plexus palsy. J Neurosurg. 2001 Mar;94(3):386-91.

17. El-Gammal TA, Abdel-Latif MM, Kotb MM, El-Sayed A, Ragheb YF, Saleh WR, Geith MA, Abdel-Ghaffar HS. Intercostal nerve transfer in infants with obstetric brachial plexus palsy. Microsurgery. 2008;28(7):499-504.

18. Luo PB, Chen L, Zhou CH, Hu SN, Gu YD. Results of intercostal nerve transfer to the musculocutaneous nerve in brachial plexus birth palsy. J Pediatr Orthop. 2011 Dec;31(8):884-8.

19. Blaauw G, Slooff AC. Transfer of pectoral nerves to the musculocutaneous nerve in obstetric upper brachial plexus palsy. Neurosurgery. 2003 Aug;53(2):338-41; discussion 341-2.

20. Wellons JC, Tubbs RS, Pugh JA, Bradley NJ, Law CR, Grabb PA. Medial pectoral nerve to musculocutaneous nerve neurotization for the treatment of persistent birth-related brachial plexus palsy: an 11-year institutional experience. J Neurosurg Pediatr. 2009 May;3(5):348-53.

21. Kawabata H, Kawai H, Masatomi T, Yasui N. Accessory nerve neurotization in infants with brachial plexus birth palsy. Microsurgery. 1994;15(11):768-72.

22. Blaauw G, Sauter Y, Lacroix CL, Slooff AC. Hypoglossal nerve transfer in obstetric brachial plexus palsy. J Plast Reconstr Aesthet Surg. 2006;59(5):474-8. Epub 2006 Mar 22.

23. Oberlin C, Ameur NE, Teboul F, Beaulieu JY, Vacher C. Restoration of elbow flexion in brachial plexus injury by transfer of ulnar nerve fascicles to the nerve to the biceps muscle. Tech Hand Up Extrem Surg. 2002 Jun;6(2):86-90.

24. Oberlin C, Durand S, Belheyar Z, Shafi M, David E, Asfazadourian H. Nerve transfers in brachial plexus palsies. Chir Main. 2009 Feb;28(1):1-9. Epub 2008 Dec 25.

25. Allieu Y, Clauzel AM, Mekhaldi A, Triki F. [Consequences of adult brachial plexus paralysis and its surgical treatment on respiratory function]. Rev Chir Orthop Reparatrice Appar Mot. 1986;72(6):455-60. French.

26. Toussaint CP, Zager EL. The double fascicular nerve transfer for restoration of elbow flexion. Neurosurgery. 2011 Mar;68(1)(Suppl Operative):64-7; discussion 67.

27. Curtis C, Stephens D, Clarke HM, Andrews D. The active movement scale: an evaluative tool for infants with obstetrical brachial plexus palsy. J Hand Surg Am. 2002 May;27(3):470-8.

28. Ray WZ, Pet MA, Yee A, Mackinnon SE. Double fascicular nerve transfer to the biceps and brachialis muscles after brachial plexus injury: clinical outcomes in a series of 29 cases. J Neurosurg. 2011 Jun;114(6):1520-8. Epub 2011 Feb 25.