SCIENTIFIC ARTICLE

Outcomes of Late Microsurgical Nerve Reconstruction for Brachial Plexus Birth Injury

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Purpose Microsurgical nerve reconstruction has been advocated between 3 and 9 months of life in select patients with brachial plexus birth injury (BPBI), yet some patients undergo indicated surgery after this time frame. Outcomes in these older patients remain poorly characterized. We analyzed outcomes of nerve reconstruction performed after 9 months of age and hypothesized that (1) Active Movement Scale (AMS) scores improve after surgery, and (2) there are no differences in AMS scores between patients undergoing nerve transfers versus those undergoing nerve grafting.

Methods From 2000 to 2014, 750 patients at 6 U.S. centers were prospectively enrolled in a multicenter database. We included patients treated with nerve reconstruction after 9 months of age with minimum 12 months' follow-up. Patients were evaluated using AMS scores. To focus on the results of microsurgery, only outcomes prior to secondary surgery were analyzed. We analyzed baseline variables using bivariate statistics and change in AMS scores over time and across treatment groups using linear mixed models.

Results We identified 32 patients (63% female) with median follow-up of 29.8 months. Median age at microsurgery was 11.2 months. Twenty-five (78%) had an upper trunk injury. Compared with before surgery, total AMS scores improved modestly at 1 year and 2 or more years follow-up. At 1 year follow-up, AMS scores improved for shoulder function (abduction, external rotation) and elbow flexion. Between-group comparisons found no differences in total AMS scores or AMS subscales between graft and transfer groups at 1 year or 2 or more years after surgery, so we cannot recommend one strategy over the other based on our findings.

Conclusions Overall, nerve reconstruction in patients with BPBI after 9 months of age resulted in improved function over time. There was no difference in outcomes between nerve transfer and nerve graft groups and 1 or 2 or more years follow-up. *(J Hand Surg Am. 2019;■(■):1.e1-e9. Copyright © 2019 by the American Society for Surgery of the Hand. All rights reserved.)*

Type of study/level of evidence Therapeutic IV.

Key words Brachial plexus birth palsy, late surgery, nerve graft, nerve transfer, obstetrical brachial plexus palsy.

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Brachial plexus birth injury (BPBI) is common, with an estimated annual incidence of 1 per 1,000 births or approximately 5,000 new cases each year in the United States.[1–4] The reported rate of spontaneous recovery is widely variable, ranging from 49%[5] to 97%.[6] Predicting which patients will spontaneously achieve sufficient recovery for acceptable function remains a challenge.[7] As a consequence, the decision regarding whether and when to intervene surgically remains controversial.[7–11]

Microsurgical nerve reconstruction of brachial plexus injuries has typically been advocated in selected patients between 3 and 9 months of life. Some authors recommend microsurgery if patients do not gain antigravity biceps function by 3 months,[12–17] 4 months,[18] or 5 months of age.[19] Others have recommended algorithms accounting for both elbow and hand function.[7,8,10,20,21] Taking into consideration elbow flexion as well as elbow, wrist, finger, and thumb extension, Clarke and colleagues[7] developed the Toronto Test Score (TTS) to help guide the decision for early surgical treatment. Clarke et al[7,8,10,20] recommend considering microsurgery if (1) a patient's TTS is less than 3.5 at 3 months of age; (2) TTS is 3.5 or greater at 3 months of age but the patient does not show substantial improvement in elbow flexion by 6 months; or (3) TTS is 3.5 or greater at 3 months but the patient then fails the cookie test at 9 months of age.

Some patients present late with poor recovery and would have been candidates for nerve reconstruction earlier in infancy, or, as noted previously, seem to be on the desired recovery pathway only to plateau at a suboptimal level as they approach 9 to 12 months of life. These patients are potential candidates for late nerve reconstruction. However, outcomes in patients with BPBI who undergo microsurgical nerve reconstruction after 9 months of age remain poorly characterized. Furthermore, there are little comparative data to guide surgeons in the decision to perform nerve grafts or nerve transfers in these older patients. To address this, we analyzed outcomes of microsurgical nerve reconstruction performed in patients with BPBI after 9 months of age. In these older patients, we hypothesized that (1) Active Movement Scale (AMS) scores improve after surgery, and (2) there are no differences in the total AMS score at 2 or more years after surgery between patients undergoing nerve transfers versus those undergoing nerve grafting.

TABLE 1. Active Movement Scale (AMS)

Gravity Eliminated	Score
No contraction	0
Contraction, no motion	1
< 50% motion	2
> 50% motion	3
Full motion	4
Against Gravity	**Score**
< 50% motion	5
> 50% motion	6
Full motion	7

MATERIALS AND METHODS

Data source

We obtained data from the TOBI (Treatment and Outcomes of Brachial Plexus Injuries) database for patients enrolled from 2000 to 2014. Maintained by the TOBI study group, the database contains prospectively collected data for infants with BPBI from 6 regional medical centers: Boston Children's Hospital (Boston, MA), Akron Children's Hospital (Akron, OH), Children's Healthcare of Atlanta (Atlanta, GA), Children's Hospital Los Angeles (Los Angeles, CA), Cincinnati Children's Hospital (Cincinnati, OH), and Shriners Hospitals for Children in Northern California (Sacramento, CA). From 2000 to 2015, these 6 medical centers contributed records for 750 patients to the TOBI BPBI database. Each record contains information characterizing the patient's demographics, perinatal history, physical examination at each recorded clinical visit (AMS scores,[20] TTS,[7] and Mallet scores[22]), and surgical treatment rendered (nerve grafts, nerve transfers, tendon transfers, humeral osteotomy, or other surgical procedures), including specifics of each surgical intervention. The AMS is a validated measurement tool for evaluating infants with BPBI that does not require extensive training[20] (Table 1). All centers participated in standardization of AMS scoring at the outset of the TOBI study. Of note, the AMS score is designed to report range of motion as a percentage of available range, taking any contractures of the shoulder and elbow into account.

Data integrity

The TOBI database uses standardized paper case report forms and employs a Web-based data management system. The details of the study protocol, including question-specific validation criteria, are programmed into the data management system to prevent logical errors. Prior to the start of analysis, we further eliminated outliers resulting from data collection or entry errors.

Selection criteria

We included all patients with BPBI who underwent microsurgical reconstruction at 9 or more months of age and had at least 12 months of follow-up after surgery. Of the 60 patients who underwent microsurgical nerve reconstruction after 9 months of life, 28 patients had less than 12 months of follow-up and were excluded. The remaining 32 patients met the selection criteria and were included. To focus exclusively on the outcomes of microsurgical nerve reconstruction, only outcomes prior to any secondary surgeries, such as tendon transfers or osteotomies, were analyzed.

Data elements

For all patients meeting the selection criteria, we abstracted information for our main outcome (recovery in the form of AMS scores), main predictor (nerve graft vs nerve transfer), and additional covariates including patient demographics and perinatal history.

Our primary outcome measure was postoperative motor function based on clinical examination at the latest follow-up, at least 12 months after surgery. For patients who ultimately underwent secondary surgery (eg, tendon transfer or humeral osteotomy), we only included data prior to any secondary procedures. Our main predictor was a binary variable indicating whether a nerve transfer or grafting procedure was performed. An AMS score of 6 or greater has previously been defined as functional."[23] Therefore, an AMS score of 6 or greater was used as a secondary outcome measure to assess whether the improvements seen after surgery were likely to be clinically relevant.

Statistical methods

Baseline patient characteristics were summarized for all patients by mean and SD or median and interquartile range (IQR) for continuous characteristics and by frequency and percent for categorical characteristics. Bivariate comparisons were conducted between nerve graft and nerve transfer treatment groups to identify differences in motor recovery as well as differences in baseline variables. Comparisons were conducted using Student *t* test, Mann-Whitney U-test, Fisher exact test, or the Cochran-Armitage test for rend, as appropriate.

Change in AMS total score and AMS subscales from preoperative to 1 and 2 or more years of follow-up was analyzed across treatment groups using linear mixed model analysis with either an unstructured or a compound symmetry correlation structure based on model fit. Linear mixed models account for the correlation between repeated measurements on the same subjects and incorporate all data regardless of missing data. Model fit was assessed using likelihood ratio tests and Akaike information criterion. The change in AMS total score and AMS subscales was also summarized for complete pairs of preoperative and follow-up data at each time point by mean differences and 95% confidence intervals. Pairwise comparisons across treatment groups were conducted at each time point using Mann-Whitney U-tests. Subgroup analysis was conducted on patients with isolated shoulder spinal accessory nerve (SAN) to suprascapular nerve (SSN) transfer. All tests were 2-tailed and statistical significance was defined as P less than .05.

A power analysis was conducted assuming unequal variance and a group allocation ratio of 1:2 (nerve graft—to—nerve transfer). It was found that samples of size 7 and 13, respectively, would provide 80% power to detect a difference of 20% across groups in the change in total AMS score from baseline to at least 12 months of follow-up and samples of 5 and 9, respectively, would provide 80% power to detect differences in the change in AMS score across groups of 25%.

Source of funding

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RESULTS

We identified 32 patients (63% female; 52% birth weight $>$ 4,000 g) treated with microsurgical nerve reconstruction after 9 months of age and with a median follow-up of 29.8 months (range, 12.6—163.5 months). Median age at presentation was 2.7 months and median age at microsurgery was 11.2 months (range, 9.1—22.3 months). Twenty-six patients (76%) had an upper trunk injury (Narakas groups 1 or 2); the remaining 8 (24%) had a more extensive pattern of injury (Narakas groups 3 or 4). Compared with those with upper trunk injury (Narakas 1 or 2), patients with more extensive brachial plexus injuries (Narakas group 3 or 4) presented later (mean, 7.1 vs 3.0 months; $P < .05$) and tended to have surgery earlier (mean, 11.1 vs 12.8 months; $P = .07$), but were otherwise comparable in terms of baseline characteristics (Table 2).

Indications for surgery, as recorded by the surgeon at the time of the operation, are listed in Table 3. Reasons for undergoing microsurgical nerve reconstruction after 9 months of age were varied, and several subjects had more than 1 reason (Table 4). Only 9 of 32 subjects (28%) presented to a participating center after 9 months of age. Surgery was delayed in 4 (12%) owing to loss to follow-up after their initial presentation, and an additional 7 (22%)

TABLE 2. Baseline Characteristics by Treatment Group

Characteristic	Nerve Transfer (n = 20)		Nerve Graft (n = 12)	
	Frequency	%	Frequency	%
Age at presentation, mo (mean ± SD)	3.4	± 3.30	4.3	± 3.56
Age at microsurgery, mo (mean ± SD)	13.5	± 3.99	10.7	± 0.89
Sex (% female)	11	55	9	75
Side (% right)	12	60	9	75
Birth weight > 4000 g (n = 31*)	10	53	6	50
Vaginal vertex presentation (n = 31*)	19	95	11	100
Forceps or vacuum delivery	5	25	3	25
Maternal gestational diabetes	7	37	3	27
Preoperative Narakas group				
1	9	45	3	25
2	7	35	6	50
3	3	15	2	17
4	1	5	1	8
Baseline AMS total score (median [IQR])	80	79−90	77	77−83

*The number in parentheses (n =) represents the number of patients with available data for the given characteristic.

had a delay in a planned surgical date for medical or social reasons. Roughly 50% of patients had later surgery owing to an unusual recovery pattern including dissociative recovery (eg, recovery of shoulder but not elbow function), an unexpected plateau in recovery, or an isolated failure of shoulder external rotation recovery.

Twenty patients (63%) underwent treatment with nerve transfer and 12 were treated with grafting. A variety of nerve grafts and transfers were performed (Table 5). Two subjects who had both grafts and transfers were considered to have a grafting strategy for their surgery, and so were included in the grafting group. One of these subjects underwent transfer of intercostal nerves to the musculocutaneous nerve, along with grafts from C5 and C6 to distal targets including the axillary nerve and the lower trunk. The other subject underwent transfer of the SAN to the SSN, along with grafts from C4 and C5 to the upper and middle trunk. No patient underwent revision nerve surgery; no complications were noted. Patients in the nerve grafting group were younger at microsurgery than the nerve transfer group (10.7 vs 13.5 months; $P < .05$); patient characteristics were otherwise similar between treatment groups (Table 2). With the exception of elbow flexion, which was better in the nerve transfer group (4.9 vs 3.1; $P < .05$), preoperative AMS scores were similar between nerve transfer and nerve graft groups (Table 2).

Among all patients, total AMS scores improved from preoperative to 1 year of follow-up ($P < .05$) but showed no significant improvement from 1 to 2 or more years ($P = .10$) (Fig. 1). Median total AMS score improved from a baseline of 79 (IQR, 63−88) to 89 (IQR, 7−95) at 1 year and finally 94 (IQR, 87−99) at 2 or more years of follow-up. There was no difference in the change in outcomes across groups over time ($P = .53$). There were 22 subjects with at least 2 years of follow-up after surgery. These subjects demonstrated an average improvement of 20% in their total AMS score at final follow-up. Of these, only 1 subject had no change and another subject had a minimally negative change from a total score of 100 before surgery to a 98 at 2.5 years of follow-up. Both subjects had undergone isolated transfer of the SAN to the SSN, one at age 14 months and the other at age 22 months. In the 10 subjects with only 1 year follow-up, 2 had a negative change in AMS score, both within 4 points (4%) of their preoperative AMS score. One of these patients had undergone multiple nerve transfers at 9 months of age, and the other had undergone a nerve grafting procedure at 10 months of age. Neither subject was available for later follow-up. At final follow-up, total AMS score improved by 19% in the patients who received nerve transfers compared with 14% in the patients who received nerve grafts. The average percent improvements in specific AMS subscales for the 2 treatment groups are presented in Table 6.

TABLE 3. Indications for Nerve Surgery

Indication for Surgery	Nerve Transfer (n = 20)		Nerve Graft (n = 12)	
	Frequency	%	Frequency	%
Lack of antigravity elbow flexion	8	40	10	83
TTS < 3.5	1	5	4	33
Horner syndrome	0	0	1	8
Flail limb	0	0	0	0
Lack of shoulder function	1	5	0	0
Isolated lack of shoulder external rotation	10	50	0	0

TABLE 4. Reasons for Undergoing Microsurgical Nerve Reconstruction After 9 Months of Age

Reason for Late Surgery	n = 32 (%)*
Presentation after age 9 mo	9 (28)
Loss to follow-up after initial evaluation	4 (12)
Delay in planned surgery	7 (22)
Unusual recovery pattern	17 (53)
Dissociative recovery/late plateau	7 (22)
Isolated failure of external rotation recovery	10 (31)

*Total does not equal 100% because some subjects had more than 1 reason for late surgery.

The improvements for total score as well as several relevant AMS subscales are presented in Table 7. For shoulder abduction, shoulder flexion, and elbow flexion, the subjects who received nerve transfers started with a higher average and also demonstrated a higher average at final follow-up. For shoulder external rotation, those who received transfers started with a lower average score (0 vs 2), and ended with an average score of 6, compared with a final average score of 3 for those who received grafts. This disparate result most likely reflects the outcome of the subjects included in the transfer group who underwent an isolated SAN-to-SSN transfer.

As described previously, an AMS score of 6 or greater for any given movement has been described as a functional score. Using this criterion, at final follow-up, 12 of 17 (71%) of nerve transfer subjects had achieved functional AMS scores for shoulder abduction and flexion, and 9 of 17 (53%) had achieved functional scores for external rotation. In contrast, only 20% of subjects (1 of 5 with available data) in the nerve grafting group achieved the same functional status. The majority of subjects in both groups achieved functional elbow flexion (15 of 17, 88% of transfers; and 5 of 5, 100% of grafts) as well as functional elbow extension (15 of 17, 88% of transfers, and 4 of 5, 80% of grafts) (Table 8).

Within the transfer group, isolated SAN-to-SSN transfer was performed in 10 patients, of whom 9 had 1 -year and 2 or more years of follow-up. Compared with preoperative measurement, shoulder external rotation AMS subscale improved over time. At 2 or more years of follow-up, there was an average increase of 5 points over preoperative measurement in shoulder external rotation (95% CI, 3.2−6.1; $P < .05$), with 5 of 9 (56%) subjects reaching an AMS score of 6 or 7.

DISCUSSION

Microsurgical nerve reconstruction is advocated in select patients with BPBI between 3 and 9 months of life. For a variety of reasons such as late presentation, dissociative recovery, medical comorbidities, and parental consent, some patients may undergo indicated surgery after this time frame. In BPBI patients older than 9 months, outcomes of nerve reconstruction have been poorly characterized, such that the surgeon may question when it is too late to perform primary nerve surgery. In addition, there are little comparative data to guide surgeons in the decision to perform sural nerve grafting versus distal nerve transfers in this older age group.

Our work supports that of Chuang and colleagues,[21] who reported on 10 patients with BPBI who underwent primary nerve reconstruction after 1 year of age, including both nerve grafts and nerve transfers. The authors reported improved shoulder and elbow function in this group and concluded that late primary nerve surgery was indicated if poor shoulder and elbow function persisted at 1 year of age. In our group of 32 subjects, we also found improvements in shoulder and elbow function in patients treated with both microsurgical nerve grafting as well as nerve transfers after 9 months of age. As in

TABLE 5. Microsurgical Reconstruction Procedures With Nerve Grafts and Transfers

Sural Nerve Grafting (n = 12)	Number of Procedures
C4 root	
To PDUT	1
C5 root	
To C8	2
To middle trunk	1
To ADUT	5
To PDUT	8
To SSN	6
To radial nerve	1
To phrenic nerve	1
C6 root	
To C8	1
To T1	1
To middle trunk	1
To ADUT	7
To PDUT	5
C7 root	
To middle trunk	4
Nerve Transfer (n = 20)	
SAN to SSN	17
Oberlin transfer*	8
Radial to axillary	3
Other	
SAN to ADUT	1
Median nerve to posterior interosseous nerve	1
Ulnar nerve to radial nerve	1
ICN to MCN	1
Medial cord to axillary nerve	1

ADUT, anterior division of upper trunk; ICN, intercostal nerve; MCN, musculocutaneous nerve; PDUT, posterior division of upper trunk.

*Oberlin transfer includes ulnar or median nerve transfer to biceps nerve, brachialis nerve, or MCN.

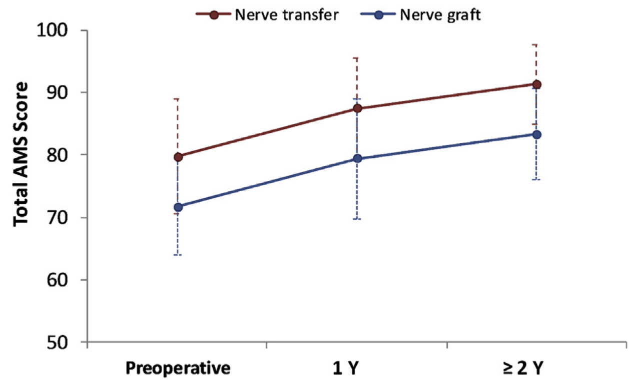

FIGURE 1: Linear mixed model for change in total AMS score over time by treatment group. Bars represent the 95% confidence interval about the model estimates at each time point.

other similar studies, the subjects in our study represent a heterogeneous mix of patients who would have been offered surgery had they presented earlier, along with those who were seen early, followed diligently, and experienced plateaus or dissociative recovery and were then offered surgery. We found modest gains in AMS scores overall, with improvement in total AMS score from a median of 79 before surgery to 94 at 2 or more years after surgery, out of a possible 105 points on the AMS. It is important also to note, however, that, although no subjects deteriorated in a clinically meaningful way, 4 of 32 subjects did not improve following surgery.

Distal nerve transfers are increasingly popular in the treatment of BPBI, and there are several favorable reports on late nerve transfer surgery. El Gammal et al[24] reported on 19 cases of late-presenting patients with BPBI who underwent nerve transfers at an average age of 41 months of age. Nerve transfer for elbow flexion resulted in motor recovery, with 10 of 11 cases achieving AMS grade 6 for elbow flexion. Al-Qattan et al[25] reported a series of 10 patients with upper plexus injuries who presented late and underwent median nerve–to–biceps motor branch nerve transfer at an average age of 16 months. Nine of 10 patients achieved at least AMS grade 6 elbow flexion. Ladak et al[26] reported improvements in both shoulder and elbow function in 10 patients aged 10 to 18 months who underwent triple nerve transfer (SAN to SSN; partial radial-to-axillary nerve; partial ulnar- or median-to-musculocutaneous nerve).

Despite the encouraging results of nerve transfers, there are little comparative data to guide surgeons as to whether distal nerve transfers are preferable to sural nerve grafting in patients with BPBI who are older than 9 months of age. Our analysis showed BPBI patients who underwent nerve transfer after 9 months of age had similar results to those who underwent nerve grafting, so we are not able to recommend one strategy over another. Although a higher percentage of transfer patients reached functional AMS scores for their shoulder function (Table 8), this may be due to these patients having less severe injuries before surgery. We are very hesitant to make any recommendations regarding nerve grafts versus transfers in this older age group based on this study because we did not set out to

TABLE 6. Percent Change in AMS Total and AMS Subscales by Treatment Group

	Nerve Transfer				Nerve Graft			
	Baseline to 1 Y		Baseline to ≥ 2 Y		Baseline to 1 Y		Baseline to ≥ 2 Y	
Measurement	%	95% CI	%	95% CI	%	95% CI	%	95% CI
Total AMS score	19	7 to 31	19	8 to 29	22	−9 to 54	14	5 to 24
AMS subscales								
Shoulder								
Abduction	38	1 to 76	19	−1 to 39	24	−19 to 67	36	−53 to 125
Flexion	43	1 to 85	24	−5 to 52	8	−31 to 47	33	−59 to 126
External rotation	50	−19 to 119	85	26 to 144	41	2 to 80	−10	−78 to 58
Elbow								
Flexion	54	−5 to 114	47	−16 to 110	50	−11 to 111	91	38 to 143
Extension	40	0 to 80	55	−11 to 121	7	−27 to 41	0	−15 to 15

95% CI, 95% confidence interval.

TABLE 7. Summary of AMS Score Measurements by Time Point by Treatment Group

Nerve Transfer	Preoperative (n = 20)		1 Y (n = 17)		≥ 2 Y (n = 17)	
Measurement	Median	IQR	Median	IQR	Median	IQR
Total AMS score	80	79−90	93	91−99	95	93−99
AMS subscales						
Shoulder						
Abduction	5	5−6	6	6−7	6	6−6
Flexion	5	5−6	6	6−6	6	6−6
External rotation	0	0−2	3	2−5	6	5−6
Elbow						
Flexion	6	6−7	6	6−7	7	7−7
Extension	6	6−7	7	7−7	6	6−7
Nerve Graft	**Preoperative (n = 12)**		**1 Y (n = 11)**		**≥2 Y (n = 5)**	
Measurement	**Median**	**IQR**	**Median**	**IQR**	**Median**	**IQR**
Total AMS score	77	77−83	84	84−88	88	88−95
AMS subscales						
Shoulder						
Abduction	3	3−5	3	3−4	5	5−5
Flexion	3	3−5	3	3−3	5	5−5
External rotation	2	2−2	3	3−3	3	3−3
Elbow						
Flexion	3	3−4	5	4−6	6	6−6
Extension	7	7−7	7	7−7	7	7−7

compare the 2 strategies and there are likely many confounding factors affecting this comparison. More investigation into this question is certainly needed.

Patients undergoing isolated SAN-to-SSN transfers represent a separate category—infants with a lesser severity of nerve injury and at least partial reinnervation of affected muscles. Our study included 10 patients who underwent this procedure. In the 8 patients who had isolated SAN-to-SSN transfer with at least 2 years of follow-up, we found significantly

TABLE 8. Proportions of Patients With AMS Subscale Values of 6 or More by Time Point and Treatment Group

	Nerve Transfer						Nerve Graft					
	Baseline (n = 20)		1 Y (n = 17)		$\geq$ 2 Y (n = 17)		Baseline (n = 12)		1 Y (n = 11)		$\geq$ 2 Y (n = 5)	
Nerve Graft	Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Shoulder												
Abduction	6	30	11	65	12	71	0	0	2	18	1	20
Flexion	6	30	11	65	12	71	2	17	1	9	1	20
External rotation	0	0	4	24	9	53	0	0	1	9	1	20
Elbow												
Flexion	12	60	13	77	15	88	1	8	3	27	5	100
Extension	11	55	14	82	15	88	10	83	8	73	4	80

improved shoulder external rotation AMS scores. This is in line with van Ouwerkerk et al,[27] who examined early versus late results of SAN-to-SSN transfer in 54 patients with BPBI. The authors found no difference in mean active shoulder external rotation when comparing patients treated with surgery before or after 12 months of age. Our work supports the idea that the isolated SAN-to-SSN transfer is likely to be successful even in this much older age group.

We recognize several limitations to our study. First, with only 32 patients meeting selection criteria, our study may suffer from biases including selection bias and unverified confounding. Compared with the nerve transfer group, there were fewer patients in the nerve graft group at each time point, which may mean that the sample is not representative of these populations. Furthermore, the nerve graft subjects were followed for a median of 16.6 months compared with a median of 29.8 months in the nerve transfer group. This may have decreased our ability to detect improvements in the nerve graft group. Given that the results of nerve reconstruction improve over time, our results may not represent the full benefit of these procedures. The use of the AMS to describe results has limitations as well. Although the AMS is designed to take contractures into account, it may not fully compensate for contractures and deformity of the glenohumeral joint. Because imaging was not a part of this study, it is possible that more subjects in one group developed glenohumeral dysplasia, which may have influenced our results.

Despite these limitations, this work is based on data obtained from multiple centers, with surgical details and physical examination scores recorded at the time of each patient encounter. The small numbers are due to strict inclusion criteria, which is both a benefit and a drawback of our methodology. Although it is common in the literature to report results achieved in BPBI patients after both microsurgery and secondary surgeries, we only included outcomes prior to secondary surgery. This allowed us to evaluate the results of nerve reconstruction as specifically as possible despite the inevitable heterogeneity of the BPBI population. However, this did limit the size of our cohort of eligible patients. It is possible that this restricted group introduced additional bias into our results.

Our analysis of 32 patients with BPBI suggests encouraging results overall—nerve reconstruction in patients after 9 months of age resulted in modest improvements in function over time, regardless of surgical strategy. Also, reassuringly, no patient's function was made clinically worse by attempting a late reconstructive surgery. Further study is warranted to assess long-term outcomes and help clarify the role of nerve transfers versus grafts in these older patients.

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REFERENCES

1. Foad SL, Mehlman CT, Ying J. The epidemiology of neonatal brachial plexus palsy in the United States. *J Bone Joint Surg Am*. 2008;90(6):1258−1264.
2. Gilbert WM, Nesbitt TS, Danielsen B. Associated factors in 1611 cases of brachial plexus injury. *Obstet Gynecol*. 1999;93(4):536−540.
3. Mollberg M, Hagberg H, Bager B, Lilja H, Ladfors L. High birth-weight and shoulder dystocia: the strongest risk factors for obstetrical brachial plexus palsy in a Swedish population-based study. *Acta Obstet Gynecol Scand*. 2005;84(7):654−659.
4. Chauhan SP, Blackwell SB, Ananth CV. Neonatal brachial plexus palsy: incidence, prevalence, and temporal trends. *Semin Perinatol*. 2014;38(4):210−218.
5. Bager B. Perinatally acquired brachial plexus palsy—a persisting challenge. *Acta Paediatr*. 1997;86(11):1214−1219.
6. Nocon JJ, McKenzie DK, Thomas LJ, Hansell RS. Shoulder dystocia: an analysis of risks and obstetric maneuvers. *Am J Obstet Gynecol*. 1993;168(6 Pt 1):1732−1737; discussion 1737−1739.
7. Michelow BJ, Clarke HM, Curtis CG, Zuker RM, Seifu Y, Andrews DF. The natural history of obstetrical brachial plexus palsy. *Plast Reconstr Surg*. 1994;93(4):675−680.
8. Clarke HM, Curtis CG. An approach to obstetrical brachial plexus injuries. *Hand Clin*. 1995;11(4):563−580.
9. Waters PM. Update on management of pediatric brachial plexus palsy. *J Pediatr Orthop B*. 2005;14(4):233−244.
10. Borschel GH, Clarke HM. Obstetrical brachial plexus palsy. *Plast Reconstr Surg*. 2009;124(1 Suppl):144e−155e.
11. Belzberg AJ, Dorsi MJ, Storm PB, Moriarity JL. Surgical repair of brachial plexus injury: a multinational survey of experienced peripheral nerve surgeons. *J Neurosurg*. 2004;101(3):365−376.
12. Gilbert A, Tassin JL. Surgical repair of the brachial plexus in obstetric paralysis [in French]. *Chirurgie*. 1984;110(1):70−75.
13. Gilbert A, Razaboni R, Amar-Khodja S. Indications and results of brachial plexus surgery in obstetrical palsy. *Orthop Clin North Am*. 1988;19(1):91−105.
14. Gilbert A, Brockman R, Carlioz H. Surgical treatment of brachial plexus birth palsy. *Clin Orthop Relat Res*. 1991;264:39−47.
15. Gilbert A. Long-term evaluation of brachial plexus surgery in obstetrical palsy. *Hand Clin*. 1995;11(4):583−594.
16. Narakas AO. Obstetrical brachial plexus injuries. In: Lamb DW, ed. *The Paralysed Hand*. Edinburgh, England: Churchill Livingstone; 1987:116−135.
17. Hentz VR, Meyer RD. Brachial plexus microsurgery in children. *Microsurgery*. 1991;12(3):175−185.
18. Al-Qattan MM. The outcome of Erb's palsy when the decision to operate is made at 4 months of age. *Plast Reconstr Surg*. 2000;106(7):1461−1465.
19. 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;81(5):649−659.
20. 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;27(3):470−478.
21. Chuang DC-C, Mardini S, Ma H-S. Surgical strategy for infant obstetrical brachial plexus palsy: experiences at Chang Gung Memorial Hospital. *Plast Reconstr Surg*. 2005;116(1):132−142.
22. Mallet J. Obstetrical paralysis of the brachial plexus. II. Therapeutics. Treatment of sequelae. Priority for the treatment of the shoulder. Method for the expression of results [in French]. *Rev Chir Orthop Reparatrice Appar Mot*. 1972;58(Suppl 1):166−168.
23. 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;97(5):974−982.
24. El-Gammal TA, El-Sayed A, Kotb MM, Saleh WR, Ragheb YF, El-Refai O. Delayed selective neurotization for restoration of elbow and hand functions in late presenting obstetrical brachial plexus palsy. *J Reconstr Microsurg*. 2014;30(4):271−274.
25. Al-Qattan MM, Al-Kharfy TM. Median nerve to biceps nerve transfer to restore elbow flexion in obstetric brachial plexus palsy. *Biomed Res Int*. 2014;2014:854084.
26. Ladak A, Morhart M, O'Grady K, et al. Distal nerve transfers are effective in treating patients with upper trunk obstetrical brachial plexus injuries: an early experience. *Plast Reconstr Surg*. 2013;132(6):985e−992e.
27. van Ouwerkerk WJR, Uitdehaag BMJ, Strijers RLM, et al. Accessory nerve to suprascapular nerve transfer to restore shoulder exorotation in otherwise spontaneously recovered obstetric brachial plexus lesions. *Neurosurgery*. 2006;59(4):858−867.