OPEN

PRS GLOBAL OPEN

ORIGINAL ARTICLE

Peripheral Nerve

Impact of Surgery Timing on Outcomes After Nerve Transfer to Restore Elbow Flexion

Katie Hicks, MD*
Justin Haas, BSc*
Moaath Saggaf, MD*
Christine B. Novak, PhD*
Jana Dengler, MD, MASc, FRCS(C)*†

Background: Nerve reconstruction following brachial plexus injury (BPI) is a time-sensitive procedure, and surgical delay may negatively impact muscle reinnervation and outcomes. This study investigated the impact of surgical timing on elbow flexion strength in patients with BPI undergoing nerve transfer to restore elbow flexion.
Methods: Following PRISMA guidelines, MEDLINE, Embase, and the Cochrane Library databases were systematically searched. English-language studies investigating the single fascicular transfer (SFT) or double fascicular transfer (DFT) to restore elbow flexion in BPI were included. Data were analyzed to identify the predictors of elbow flexion strength: surgery timing, age, injury level, and SFT versus DFT.
Results: The literature search identified 1051 articles. Studies (n = 31) reporting data of individual patients who underwent SFT (n = 341) or DFT (n = 67) were included; the mean age was 29.6 ± 11.2 years, time from injury to surgery was 6.5 ± 5.0 months, and follow-up was 27.1 ± 24.3 months. Good elbow flexion strength was found: Medical Research Council grade greater than or equal to 3 in 352 (86.3%) and Medical Research Council grade greater than or equal to 4 in 288 (70.6%). In the adjusted analysis, poorer motor recovery was associated with increased age ($P = 0.02$), surgical delay ($P < 0.0001$), C5-7 injuries ($P < 0.01$), and pan-plexus injuries ($P < 0.0001$). A 32% reduction in the odds of favorable motor recovery was observed with a 3-month delay to surgery. Patients who had a nerve transfer 6 months or earlier from injury had 2.4 times the odds of favorable motor recovery ($P < 0.001$).
Conclusions: SFT and DFT provide excellent elbow flexion strength in the majority of patients. Following nerve transfers in individuals with BPI, poorer motor recovery was observed with each 3-month delay to surgery. *(Plast Reconstr Surg Glob Open 2025;13:e6460; doi: 10.1097/GOX.0000000000006460; Published online 14 February 2025.)*

INTRODUCTION

Brachial plexus injuries (BPIs) are devastating injuries that commonly occur in the setting of trauma in the young, male population and frequently lead to substantial physical and psychological disability.[1,2] In the absence of an indication for early surgical exploration, such as complete transection of 1 or multiple nerves or root avulsion injury, the optimal timing of surgical intervention remains controversial. Intervening too early (<3 mo) after injury in cases that could regain spontaneous reinnervation is unnecessary, whereas delaying surgery (>12 mo) after injury may result in irreversible damage to the motor end plate and subsequent failure of muscle reinnervation. In closed traction BPIs, patients are observed with serial clinical and electrodiagnostic examinations to evaluate for evidence of recovery. In the absence of spontaneous reinnervation, surgical exploration is ideally performed between 3 and 6 months after injury.[3–5] Although this time period to intervene is the general consensus, some data suggest that earlier operative intervention may result in superior postoperative outcomes.[6] Nerve transfer

*From the *Division of Plastic, Reconstructive and Aesthetic Surgery, Department of Surgery, University of Toronto, Toronto, ON, Canada; and †Tory Trauma Program, Sunnybrook Health Sciences Centre, Toronto, ON, Canada.*

Received for publication September 11, 2024; accepted November 14, 2024.

Presented at the Canadian Society of Plastic Surgeons Annual Meeting, June 17–21, 2021 (virtual meeting), and Plastic Surgery The Meeting (ASPS) Annual Meeting, October 29, to November 1, 2021, Atlanta, GA.

DOI: 10.1097/GOX.0000000000006460

Disclosure statements are at the end of this article, following the correspondence information.

Related Digital Media are available in the full-text version of the article on www.PRSGlobalOpen.com.

procedures are typically performed between 3 and 12 months after injury to ensure that target muscle reinnervation occurs within 12–18 months after injury.[7]

The timing of surgical intervention and prioritization of restoration of upper extremity function are important principles in the management of BPI. For individuals with BPI, restoration of elbow flexion is a key function.[3] The single fascicular nerve transfer (SFT) has been used to provide elbow flexion, where a functioning fascicle from the ulnar nerve, most commonly the flexor carpi ulnaris is coapted to motor branches of the biceps brachii muscle.[8] This procedure was modified to the double fascicular transfer (DFT) and includes 2 nerve transfers: one from a functioning median nerve fascicle to the biceps branch and the other from an ulnar nerve fascicle to the brachialis branch.[9,10] The DFT may provide improved elbow flexion strength compared with the SFT.[2,5,8,11]

This study aimed to investigate the impact of surgery timing on elbow flexion strength in patients with BPIs undergoing SFT or DFT for restoration of elbow flexion. The SFT/DFT to restore elbow flexion was chosen as a model for the impact of surgical timing on nerve reconstruction because of the single joint movement of elbow flexion and assessment of strength by Medical Research Council (MRC) grade, as compared with complex joint movements involving multiple muscle groups.

MATERIALS AND METHODS

Study Registration and Guidelines

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines were followed.[12] The study protocol was registered on the PROSPERO database (registration no. CRD42021225962).[13]

Literature Search

Comprehensive searches of MEDLINE (1946: March 1, 2024), Embase (1947: March 1, 2024), and the Cochrane Library (1995: March 1, 2024) were performed. The search strategy was designed to identify all studies that evaluated final postoperative elbow flexion strength in patients undergoing SFT or DFT for BPI. (**See table, Supplemental Digital Content 1,** which displays systematic search strategies for MEDLINE, Embase, and the Cochrane Library, **http://links.lww.com/PRSGO/D786**.) Studies were excluded if data were not available for (1) time from injury to surgery or (2) final postoperative MRC grade for elbow flexion (Table 1).

Takeaways

Question: What is the impact of surgical timing on elbow flexion strength in patients with brachial plexus injury undergoing nerve transfer (NT) to restore elbow flexion?

Findings: A systematic review of single or double fascicular NT showed restoration of good elbow flexion strength (MRC ≥ 4 in 70.6%). A 32% reduction in the odds of favorable motor recovery was observed with a 3-month delay to surgery. Patients who had surgery ≤6 months from injury had 2.4 times the odds of favorable motor recovery.

Meaning: Single and double fascicular NT provides excellent elbow flexion strength in the majority of patients; earlier surgery results in better outcomes.

Independent Review Process

Two independent reviewers (K.H. and J.H.) performed title and abstract screening (n = 1046) and selected articles for full-text review (n = 105). Additional articles were identified from relevant article reference lists (n = 5). There was strong interrater reliability for full-text screening (kappa statistic, 0.89; 95% confidence interval, 0.80–0.98).[14] The 2 reviewers (K.H. and J.H.) independently completed data extraction. During the review process, interrater agreement and disagreements were determined using a consensus method and resolved by the senior author (J.D.).

Study Selection and Data Extraction

Studies that evaluated adults with BPI who underwent SFT or DFT to restore elbow flexion were reviewed. SFT was defined as a single transfer of median or ulnar nerve fascicles to the biceps or brachialis branch of the musculocutaneous nerve. DFT was defined as the transfer of fascicles from both the median and ulnar nerves to the biceps and brachialis branches of the musculocutaneous nerve. Review articles, conference proceedings, animal studies, and cadaveric studies were excluded.

Data extracted included study characteristics (study design, publication date and country, publication year); patient factors (demographics, injury level and mechanism, preoperative muscle strength); surgical factors (time to surgery, SFT, or DFT); and clinical outcomes (duration of follow-up and postoperative muscle strength). Only data reported per individual case were included for analysis. For the statistical analyses, to compare patients with C5–C6 and C5–C7 BPI to those with more extensive root involvement, the “pan plexus” group

Table 1. Inclusion and Exclusion Criteria

	Inclusion Criteria	Exclusion Criteria
Population	Patients with traumatic brachial plexus injuries	Brachial plexus birth palsy
Intervention	Single or double fascicular transfer for restoration of elbow flexion	Nerve(s) other than fascicles from median and/or ulnar nerves used to restore elbow flexion
Outcome	MRC grade for elbow flexion	No report on postoperative MRC grade for elbow flexion
Language	English articles only	
Publication type	Primary, full-text research studies	Review articles or conference proceedings

included C5–C6 with partial C7–C8, C5–C7 with partial C8, and C5–C8 with partial T1.

Quality Assessment

The Newcastle-Ottawa Scale (NOS) was used to assess the quality of the nonrandomized studies.[15] The NOS scores range from 0 to 9; studies are categorized as poor (0–1), fair (2–6), or good quality (7–9).[16] Because the majority of our included studies had no comparator group, items referring to the selection of the "nonexposed cohort" and "comparability of cohorts" were waived. Thus, for studies in our review, the maximum attainable NOS score was 6. A mean follow-up of at least 12 months was graded as acceptable.

Statistical Analysis

Categorical data were reported as frequencies and percentages, and continuous data were reported as means and SDs. The primary outcome was the MRC grade for elbow flexion strength and was categorized into 3 groups (MRC 0–2, MRC 3, and MRC 4–5). The primary exposure variable was time to surgery. Missing data were managed with a listwise deletion.

A multiple ordinal logistic regression model was built, with the MRC categories as the dependent variable. Timing of surgery, age, injury type, and nerve transfer type were covariates in the regression model. The proportional odds assumption was tested and verified using graphical methods. An analysis of variance was performed on the regression model, and the R^2 and the discrimination index were reported. A nonlinear relationship between surgical delay and the outcome was evaluated graphically using restricted cubic splines. The model with the linear relationship and the model with nonlinearity were compared using the likelihood ratio test. Based on the statistical comparison and the graphical evaluation, the model with the linear relationship was chosen in final reporting. In a secondary analysis, surgical timing was dichotomized to 6 months or less and more than 6 months. The *E* value was calculated from the odds ratio from the model to estimate the amount of unmeasured confounding. The analyses were performed using R 4.0.1 GUI 1.72 statistical analysis.

RESULTS

Literature Search Results, Quality Assessment, and Study Characteristics

The systematic literature search identified 1735 articles (Fig. 1).[17] Five additional articles were identified from a review of references. After the removal of duplicate articles, 1051 articles underwent title and abstract relevance screening, and 105 articles underwent full-text review. A total of 31 studies met the inclusion criteria for data extraction and quantitative analysis (Table 2).[18–48] Included studies were published between 1994 and 2024; study designs were cohort studies (n = 7), case-control studies (n = 1), case series (n = 20), and case reports (n = 3). The modified NOS scores were as follows: case series and case reports (n = 23)–mean 5.4, median 5; cohort and case-control studies (n = 8)–mean 5.6, median 6. Total sample patient demographics and MRC strength results are presented in Supplemental Digital Content 2. (**See table, Supplemental Digital Content 2,** which displays the injury and surgical data for included studies, **http://links.lww.com/PRSGO/D787**.)

Patient Characteristics

Table 3 summarizes the demographics of the patients included for meta-analysis (SFT, n = 341 and DFT, n = 67). The mean age was 29.6 ± 11.2 years, the mean time from injury to surgery was 6.5 ± 5.0 months, and the mean follow-up was 27.1 ± 24.3 months. All patients who were included had no elbow flexion preoperatively (MRC grade 0).

Postoperative Elbow Strength

Good elbow flexion strength was reported in most patients: MRC greater than or equal to 3 in 86.3% and MRC greater than or equal to 4 in 70.6% (Table 4). Table 5 presents the postoperative MRC elbow flexion strength based on (1) type of nerve transfer, (2) level of injury, (3) surgery timing, and (4) age.

Impact of Timing of Surgery

The logistic regression model revealed that a 3-month delay in surgery had a 32% reduction in the odds of a clinically significant change in elbow flexion strength (ie, from 0–2 to 3 or from 3 to 4–5), on average, after accounting for other variables in the model ($P < 0.0001$). With longer delays to surgery, the overall odds reduction of a favorable motor recovery increased ranging from 53% with a 6-month delay to 99% with a 36-month delay (Table 6). In our second model, the timing of surgery was dichotomized to 6 months or less or more than 6 months. Procedures performed more than 6 months after injury resulted in a 59% odds reduction of a favorable recovery, on average, after accounting for other variables in the model ($P < 0.001$). (**See table, Supplemental Digital Content 3,** which displays changes in the odds ratio when dichotomizing time to surgery to ≤6 versus >6 months, **http://links.lww.com/PRSGO/D788**.)

The *E* value for the odds ratio was 2.48. The likelihood ratio test indicated that the model with the nonlinear versus linear relationship between surgical delay and the MRC scale did not explain the outcome better ($P = 0.91$).

The median time from injury to surgery was 8 months (interquartile range [IQR], 6 mo) in patients who achieved MRC 0–2 elbow flexion strength compared with 5 months (IQR, 3 mo) in patients who achieved MRC grade 3 elbow flexion strength or higher ($P < 0.0001$).

Impact of Age

With a 10-year increase in age, there was a 22% reduction in the odds of achieving a clinically significant change in the MRC scale ($P = 0.02$), and this trend continued with increasing age spans: 20-year, 38%; 30-year, 52%; and 40-year, 62% ($P = 0.04$) (Table 7).

The median age was 29.5 years (IQR, 13 y) in patients reaching MRC 0–2 elbow flexion strength, compared with 26 years (IQR, 13 y) in those with MRC 3 elbow flexion strength or higher ($P = 0.01$).

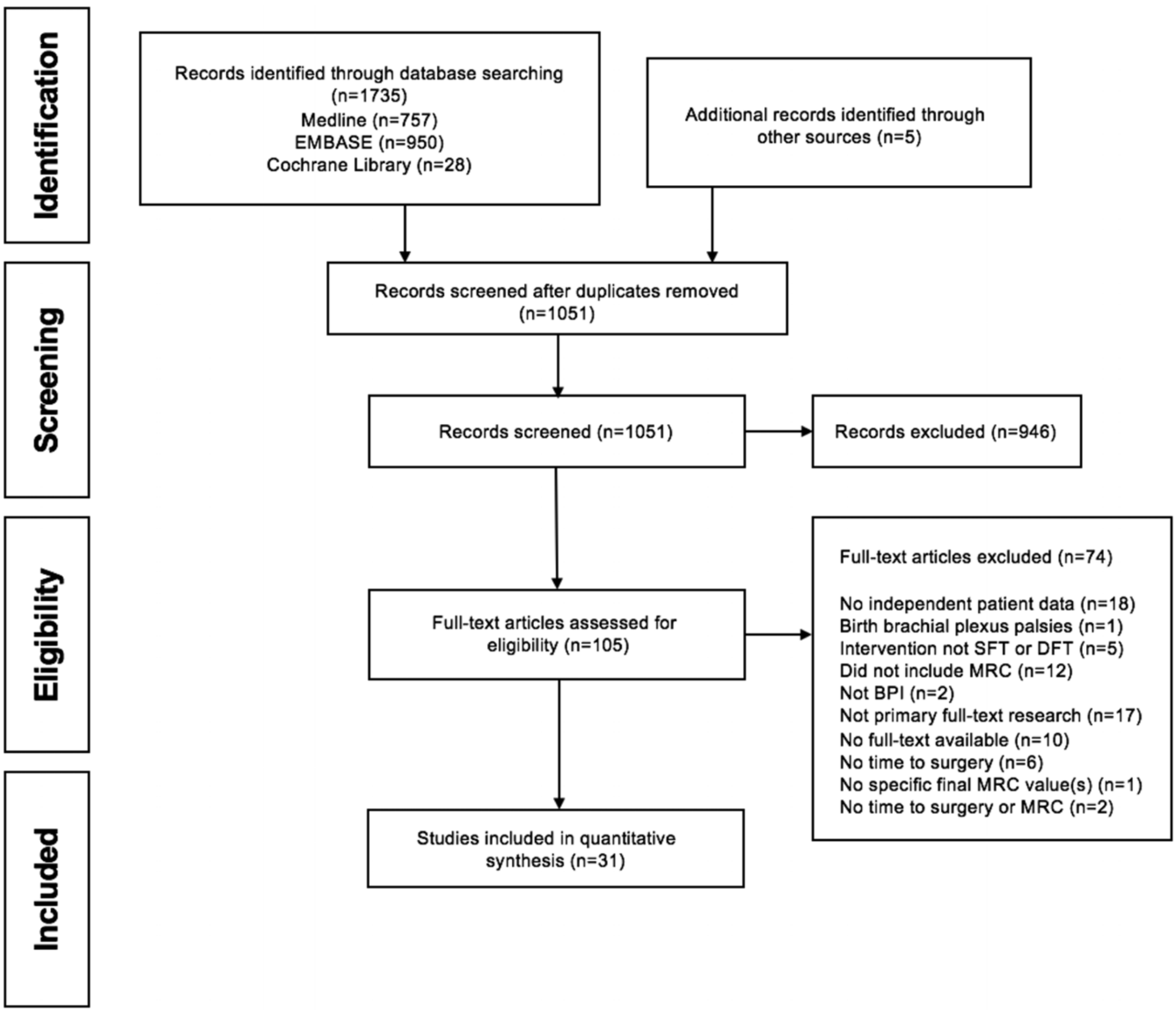

Fig. 1. PRISMA flow diagram.[17]

Effect of Level of Injury and Type of Nerve Transfer

The level of injury significantly impacted the final MRC outcome. Comparing patients with a C5–C6 injury to C5–C7 and pan-plexus injuries, the odds of achieving a favorable motor recovery were reduced in C5–C7 injuries by 52% ($P = 0.004$) and in pan-plexus by 98% ($P < 0.0001$). There was no statistically significant difference in patients who sustained isolated musculocutaneous nerve injuries compared to those with C5–C6 injuries ($P = 0.46$). Patients who underwent a DFT had 2.1 odds of achieving a clinically significant change in the MRC score compared with an SFT ($P = 0.04$). Time to surgery was significantly longer for the SFT cohort (6.7 ± 5.3 mo) than for the DFT cohort (5.4 ± 2.8 mo) ($P = 0.02$).

DISCUSSION

The scientific literature is inconclusive regarding the optimal time to restore lost function in individuals with traumatic BPIs. Although it is generally accepted that intervening around 6 months postinjury is appropriate if there is no evidence of reinnervation,[3–5] no robust outcome data are available to guide decision-making. In our systematic review of postoperative elbow flexion strength in patients after SFT or DFT, we found several factors were associated with worse motor recovery including older age, longer time from injury to surgery, and C5–C7 and pan-plexus injuries (compared with C5–C6 injuries). Significant reductions in the odds of a favorable motor recovery were found with each 3-month delay to surgery.

Restrictions in surgical resources can lead to operating room shutdowns for elective cases.[49] As an advocacy initiative to provide optimal care to patients with complex nerve injuries, the Canadian Peripheral Nerve Research Collaborative recommended immediate referral of patients with complex nerve injuries, to avoid delays in assessment and triaging, especially for patients requiring urgent surgical intervention.[50] In our study, there was a continual decline in the odds of a favorable

Table 2. Study Characteristics of Included Studies

Study (n = 31)	Study Design	Modified NOS	Patients (N)	Age, y (Mean ± SD)	Patients Eligible for Meta-analysis (N)
Coulet et al[18]	Cohort	6	23	28.8 ± 10.2	23
Moses et al[19]	Case report	5	1	25	1
Leechavengvongs et al[20]	Case series	6	15	26.9 ± 12.0	15
Liu et al[21]	Cohort	6	10	35.3 ± 11.3	10
Kakinoki et al[22]	Cohort	6	8	37.9 ± 15.9	8
Ray et al[23]	Case series	6	29	34.9 ± 15.7	26
Lovy et al[24]	Case control	6	18	37.9 ± 16.1	18
Venkatramani et al[25]	Case series	6	15	35.6 ± 12.3	15
Estrella[26]	Case series	6	9	31.9 ± 9.7	9
Zyaei and Saied[27]	Case series	6	10		10
Frueh et al[28]	Case series	6	6	39.5 ± 11.3	6
Cho et al[29]	Cohort	6	23	27.7 ± 8.7	23
Nagano et al[30]	Case series	6	6	29.5 ± 11.9	6
Leechavengvongs et al[31]	Case series	5	32	27.8 ± 7.6	32
Oberlin et al[32]	Case series	6	4	25 ± 6.1	3
de Amoreira and da Silva[33]	Case series	6	13	24.1 ± 6.5	13
Maricq et al[34]	Case series	5	5	32.2 ± 14.2	5
Sedain et al[35]	Case series	6	9	29.1 ± 6.1	9
Nath et al[36]	Case series	4	40	25 ± 7.2	39
Liverneaux et al[37]	Case series	5	10	27.2 ± 8.0	10
Kokkalis et al[38]	Cohort	5	21	26.5 ± 10.8	21
Ren et al[39]	Cohort	6	4	28.7 ± 10.0	3
De Rezende et al[40]	Case series	5	19	28.7 ± 7.8	19
Goubier and Teboul[41]	Case report	5	1	33	1
Johnsen and Wolfe[42]	Case report	5	1	74	1
Bhandari et al[43]	Case series	5	14	26.5 ± 6.1	14
Naito et al[44]	Case series	5	4	31.3 ± 11.0	4
Shahriar-Kamrani et al[45]	Cohort	4	9	26 ± 11.6	6
Teboul et al[46]	Case series	5	32	28.2 ± 11.3	32
Socolovsky et al[47]	Case series	6	18	30.4 ± 8.9	18
Suzuki et al[48]	Case series	5	8	29 ± 10.6	8
Total			417		408

Table 3. Patient Demographics Included in Meta-analysis

Variables	Patients Included in Meta-analysis (n = 408)
Age	
Mean ± SD, y	29.6 ± 11.2
Range, y	11–74
Injury level, n (%)	
C5–C6	260 (64.5)
C5–C7	120 (29.8)
Pan-plexus	16 (4.0)
Musculocutaneous	7 (1.7)
Type of nerve transfer, n (%)	
SFT	341 (83.6)
DFT	67 (16.4)
Time from injury to surgery	
Mean ± SD, mo	6.5 ± 5.0
Range, mo	0–75
Time to follow-up	
Mean ± SD, mo	27.1 ± 24.3
Range, mo	4–180

motor recovery with longer preoperative time to surgery and the biggest changes occurred with 3- and 6-month delays. A previous meta-analysis comparing SFT to DFT in patients with traumatic BPIs showed 94.8% of patients

Table 4. Final Postoperative Elbow Flexion Strength by MRC Grade

MRC	Patients, n (%)
0	10 (2.5)
1	18 (4.4)
2	28 (6.9)
3	64 (15.7)
4	270 (66.2)
5	18 (4.4)

operated on within 6 months reached MRC grade 3 or higher compared with only 66% operated on after 12 months.[51] This decline in function was regardless of the level of injury (C5–C6 or C5–C7) or nerve transfer procedure (SFT versus DFT). The median surgical delay was 8.5 months in patients achieving MRC grade 0–2, compared with 6 months in patients achieving MRC grade 3 or higher.[51]

Another meta-analysis comparing SFT to DFT found no significant differences in patients who reached MRC greater than or equal to 4 with early (76.9%) or late intervention after 3 months (66.2%) and similarly with 6 months from injury to surgery.[2] However, the majority (80.7%) of patients underwent nerve transfer between 3

Table 5. Distribution of Postoperative Elbow Flexion Strength (MRC) Based on Type of Nerve Transfer, Level of Injury, Age, Time to Surgery

	MRC 0–2, n (%)	MRC 3, n (%)	MRC 4–5, n (%)	Total, n
Type of nerve transfer				
SFT	50 (14.7)	56 (16.4)	235 (68.9)	341
DFT	6 (9.0)	8 (11.9)	53 (79.1)	67
Level of injury				
C5–C6	17 (6.6)	39 (15.1)	203 (78.4)	259
C5–C7	24 (20.0)	19 (15.8)	77 (64.2)	120
Pan-plexus	12 (70.6)	4 (23.5)	1 (5.9)	17
MCN	2 (28.6)	0 (0.0)	5 (71.4)	7
Time to surgery, mo				
0–3	7 (8.3)	11 (13.1)	66 (78.6)	84
4–6	11 (6.5)	25 (14.8)	133 (78.7)	169
7–9	16 (18.4)	17 (19.5)	54 (62.1)	87
10–12	11 (22)	10 (20)	29 (58)	50
>12	11 (61.1)	1 (5.6)	6 (33.3)	18
Age, y				
11–20	5 (6.7)	12 (16)	58 (77.3)	75
21–30	24 (13.2)	29 (15.9)	129 (70.9)	182
31–40	14 (17.3)	10 (12.3)	57 (70.4)	81
41–50	2 (5.9)	7 (20.6)	25 (73.5)	34
>50	9 (34.6)	4 (15.4)	13 (50)	26

MCN, musculocutaneous nerve.

Table 6. Changes in the Odds Ratio From the Multiple Ordinal Logistic Regression With Surgical Delays

Variable	Difference, mo	Odds Ratio	Overall Reduction in Odds Ratio, %	95% Confidence Intervals	*P*
Time to surgery	3	0.68	32	0.57–0.82	<0.0001
	6	0.47	53	0.32–0.68	
	12	0.22	78	0.10–0.46	
	18	0.10	90	0.03–0.31	
	24	0.05	95	0.01–0.21	
	36	0.01	99	0.001–0.10	

The model was adjusted for age, time to surgery, injury type, and type of nerve transfer.
Outcome = MRC scale. Classes: A: MRC (0–2), B: MRC (3), C: MRC (4–5).

Table 7. Changes in the Odds Ratio From the Multiple Ordinal Logistic Regression Model With Age

Variable	Difference, y	Odds Ratio	Overall Reduction in Odds Ratio, %	95% Confidence Intervals	*P*
Age	10	0.78	22	0.64–0.97	0.04
	20	0.62	38	0.41–0.93	
	30	0.48	52	0.26–0.90	
	40	0.38	62	0.16–0.87	

and 6 months after injury. In contrast, our study included patients with a broad range of surgery timing: 60.5% within 6 months postinjury, 34.0% between 0 and 3 months, 66.0% between 4 and 6 months, and the remaining 39.5% between 6 and 75 months postinjury (n = 161). This greater variability in surgical timing allowed us to make an inference on postoperative motor recovery within the eligible studies. In this study, better motor recovery was seen with nerve transfers completed within 3 months after BPI compared with 6 months.

The impact of age on outcomes after nerve reconstruction in patients with traumatic BPIs is conflicting. Previous studies have reported improved function after nerve transfer in younger patients, due to faster axon growth, enhanced sensory re-education, and less atrophy.[52,53] It has also been suggested that older patients are disadvantaged due to suboptimal nutritional status, vascular insufficiency, and age-related diminished regenerative capacity.[52,53] Results from our study support a continual decline in the likelihood of a favorable motor recovery with each 10-year increase in age. Sneiders et al[51] found no significant difference in patients achieving MRC grade 3 or higher related to age, regardless of the level of injury or type of nerve transfer. Patient ages were similar in our study and in the study by Sneiders et al. Similarly, another systematic review in a younger cohort (between the ages of 18 and 40 y) found no association between age and better functional outcomes.[2]

BPIs are complex injuries, ranging from a single nerve root to pan-plexus involvement. C5–C6 and C5–C7 injuries are often amenable to SFT or DFT, in which nerve axons have a shorter distance to the target muscle, and only need to cross a single repair site. Sneiders et al[51] reported a significantly higher proportion of patients with C5–C6 lesions achieved MRC 3 or higher compared with patients with C5–C7 injuries. The results from our study are consistent with these findings and showed a stepwise decline in the likelihood of a favorable outcome with more root involvement. This may be partially attributable to the contributions of the C7 nerve root to the nerves to flexor digitorum superficialis, one of the DFT donor nerves. Thus, the donor nerve quality is suboptimal in C5–C7 injuries.

In our review, patients with DFT were 2.1 times more likely to achieve a clinically significant change in the MRC scale, after accounting for age, time to surgery, and level of injury. These findings are consistent with the systematic review by Donnelly et al,[2] which compared DFT with ulnar fascicular transfer to restore elbow flexion and found a significantly higher proportion of patients achieved an MRC score greater than or equal to 4 in the DFT group than the ulnar nerve transfer group ($P = 0.01$). However, the time to surgery was longer for the ulnar nerve transfer cohort than the DFT cohort ($P = 0.001$), which may have impacted the final MRC scores.[2] Our study paralleled these findings. Similarly, Sneiders et al[51] evaluated patients with C5–C6 injuries and found that significantly more patients who underwent DFT compared with SFT achieved MRC grade 4 or higher ($P = 0.04$), and significantly more patients reached MRC grade 4 if operated on within 6 months of injury ($P = 0.035$). Because the SFT involves reinnervation of only the biceps brachii muscle (a primary forearm supinator and secondary elbow flexor), the DFT reinnervation of the brachialis muscle (the primary elbow flexor) and the biceps muscle contributes to improve postoperative elbow flexion strength.[11] In contrast, a retrospective review comparing SFT to DFT showed no significant difference in the proportion of patients who achieved an elbow flexion strength of MRC greater than or equal to 4 ($P = 0.28$).[54] However, a greater proportion of patients undergoing DFT (80%) versus SFT (67%) achieved MRC greater than or equal to 4, and as noted by the authors, the lack of statistical significance may be related to the statistical power.[54]

There are several limitations to our study. The heterogeneity of included articles introduces several factors that may influence outcomes, including differences in operative technique and/or postoperative protocols. MRC scores are evaluator-dependent assessments, which can introduce low interrater reliability compared with other quantitative measures of elbow flexion strength.[55] Our systematic review and meta-analysis included mostly small, retrospective cohort studies of varying quality. In addition, only SFT and DFT nerve transfers to restore elbow flexion were included. Finally, distance from nerve coaptation to the neuromuscular junction was not available and therefore not included in the statistical analysis. Strengths of this review include the comprehensive literature search, rigorous methodological approach, and strict inclusion/exclusion criteria that allowed the inclusion of studies with data of patients who underwent either SFT or DFT and had final elbow flexion strength outcomes at least 12 months after surgery.

Previous studies have assessed changes in health-related quality of life, health status, and function using the disability of the arm, shoulder, and hand and short-form 36 scores after nerve reconstruction. Patients who had surgery before 6 months consistently showed better scores compared with patients who had surgery more than 6 months postinjury.[56] Although motor and sensory recovery after nerve repair provides quantitative data regarding the physical impairments, outcomes from the patient's perspective are equally important.

CONCLUSIONS

Our study demonstrated excellent recovery of elbow flexion strength after SFT and DFT in the majority of patients. These nerve transfers should be strongly considered as a reconstructive option to restore elbow flexion after BPI with suitable donor nerves. This study highlights a gradient of reduction of a favorable motor recovery with each 3-month delay to surgery. Early surgical intervention is recommended in patients with BPI to optimize outcomes, as early as 3 months if no recovery of spontaneous motor units is seen on electromyography.

Jana Dengler, MD, MASc, FRCS(C)
Division of Plastic, Reconstructive and Aesthetic Surgery
Department of Surgery
University of Toronto
Sunnybrook Health Sciences Centre
M1-500, 2075 Bayview Avenue
Toronto, ON M4N 3M5, Canada
E-mail: jana.dengler@mail.utoronto.ca

DISCLOSURE

The authors have no financial interest to declare in relation to the content of this article.

ACKNOWLEDGMENT

The authors wish to acknowledge the contributions by Dr. Alex Kiss for his assistance with the statistical analysis, and Henry Lam (Sunnybrook Health Sciences Centre Librarian) for his assistance with the literature search.

REFERENCES

1. Jain DKA, Bhardwaj P, Venkataramani H, et al. An epidemiological study of traumatic brachial plexus injury patients treated at an Indian centre. *Indian J Plast Surg.* 2012;45:498–503.
2. Donnelly MR, Rezzadeh KT, Vieira D, et al. Is one nerve transfer enough? A systematic review and pooled analysis comparing ulnar fascicular nerve transfer and double ulnar and median fascicular nerve transfer for restoration of elbow flexion after traumatic brachial plexus injury. *Microsurgery.* 2020;40:361–369.
3. Shin AY, Spinner RJ, Steinmann SP, et al. Adult traumatic brachial plexus injuries. *J Am Acad Orthop Surg.* 2005;13:382–396.
4. Samii A, Carvalho GA, Samii M. Brachial plexus injury: factors affecting functional outcome in spinal accessory nerve transfer for the restoration of elbow flexion. *J Neurosurg.* 2003;98:307–312.
5. Brown JM, Shah MN, Mackinnon SE. Distal nerve transfers: a biology-based rationale. *Neurosurg Focus.* 2009;26:E12.
6. Jivan S, Kumar N, Wiberg M, et al. The influence of pre-surgical delay on functional outcome after reconstruction of brachial plexus injuries. *J Plast Reconstr Aesthet Surg.* 2009;62:472–479.
7. Chung KC, Waljee JF. Procedure 62: triple nerve transfer for brachial plexus injuries. In: Chung KC, ed. *Operative Techniques: Hand and Wrist Surgery.* 3rd ed. Elsevier; 2018:570–577.

8. Oberlin C, Beal D, Leechavengvongs S, et al. 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*. 1994;19:2232–2237.
9. Tung TH, Weber RV, Mackinnon SE. Nerve transfers for the upper and lower extremities. *Oper Tech Orthop*. 2004;14:213–222.
10. Weber RV, Mackinnon SE. Nerve transfers in the upper extremity. *J Am Soc Surg Hand*. 2004;4:200–213.
11. Mackinnon SE, Novak CB, Myckatyn TM, et al. Results of reinnervation of the biceps and brachialis muscles with a double fascicular transfer for elbow flexion. *J Hand Surg*. 2005;30:978–985.
12. Moher D, Liberati A, Tetzlaff J, et al; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Ann Intern Med*. 2009;151:264–269, W64.
13. National Institute for Health Research. PROSPERO: international prospective register of systematic reviews. Available at https://www.crd.york.ac.uk/PROSPERO/. Accessed December 12, 2020.
14. McHugh ML. Interrater reliability: the kappa statistic. *Biochem Med (Zagreb)*. 2012;22:276–282.
15. Stang A. Critical evaluation of the Newcastle-Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses. *Eur J Epidemiol*. 2010;25:603–605.
16. Wells GA, Shea B, O'Connell D, et al. The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. The Ottawa Hospital. Available at http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp. Accessed September 12, 2021.
17. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* 2021;372:n71.
18. Coulet B, Boretto JG, Lazerges C, et al. A comparison of intercostal and partial ulnar nerve transfers in restoring elbow flexion following upper brachial plexus injury (C5-C6±C7). *J Hand Surg Am*. 2010;35:1297–1303.
19. Moses MJ, Dai AZ, Lowe DT, et al. Case report: double Oberlin nerve transfer to restore elbow flexion following C5-C6 avulsion injury. *Oper Neurosurg (Hagerstown)*. 2019;16:23–26.
20. Leechavengvongs S, Witoonchart K, Uerpairojkit C, et al. Combined nerve transfers for C5 and C6 brachial plexus avulsion injury. *J Hand Surg Am*. 2006;31:183–189.
21. Liu Y, Zhuang Y, Xiong H, et al. Comparative study of phrenic and partial ulnar nerve transfers for elbow flexion after upper brachial plexus avulsion: a retrospective clinical analysis. *J Plast Reconstr Aesthet Surg*. 2018;71:1245–1251.
22. Kakinoki R, Ikeguchi R, Dunkan SFM, et al. Comparison between partial ulnar and intercostal nerve transfers for reconstructing elbow flexion in patients with upper brachial plexus injuries. *J Brachial Plex Peripher Nerve Inj*. 2010;5:4.
23. Ray WZ, Pet MA, Yee A, et al. 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;114:1520–1528.
24. Lovy AJ, Pulos N, Kircher MF, et al. Factors associated with failed ulnar nerve fascicle to biceps motor branch transfer: a case control study. *J Hand Surg Eur Vol*. 2019;44:913–919.
25. Venkatramani H, Bhardwaj P, Faruquee SR, et al. Functional outcome of nerve transfer for restoration of shoulder and elbow function in upper brachial plexus injury. *J Brachial Plex Peripher Nerve Inj*. 2008;03:e49–e57.
26. Estrella EP. Functional outcome of nerve transfers for upper-type brachial plexus injuries. *J Plast Reconstr Aesthet Surg*. 2011;64:1007–1013.
27. Zyaei A, Saied A. Functional outcome of ulnar nerve fascicle transfer for restoration of elbow flexion in upper brachial plexus injury. *Eur J Orthop Surg Traumatol*. 2010;20:293–297.
28. Frueh FS, Ho M, Schiller A, et al. Magnetic resonance neurographic and clinical long-term results after Oberlin's transfer for adult brachial plexus injuries. *Ann Plast Surg*. 2017;78:67–72.
29. Cho AB, Paulos RG, De Resende MR, et al. Median nerve fascicle transfer versus ulnar nerve fascicle transfer to the biceps motor branch in C5-C6 and C5-C7 brachial plexus injuries: non-randomized prospective study of 23 consecutive patients. *Microsurgery*. 2014;34:511–515.
30. Nagano Y, Kawamura D, Terkawi A, et al. Minimum ten-year outcomes of partial ulnar nerve transfer for restoration of elbow flexion in patients with upper brachial plexus injury. *J Hand Surg Asian Pac Vol*. 2019;24:283–288.
31. Leechavengvongs S, Witoonchart K, Uerpairojkit C, et al. Nerve transfer to biceps muscle using a part of the ulnar nerve in brachial plexus injury (upper arm type): a report of 32 cases. *J Hand Surg Am*. 1998;23:711–716.
32. Oberlin C, Béal D, Leechavengvongs S, et al. 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;19:232–237.
33. de Amoreira Gepp R, da Silva RT. Nerve transfer to the biceps muscle using part of the ulnar nerve: technique & report of cases. *Pan Arab J Neurosurg*. 2008;12:280–286.
34. Maricq C, Jeunehomme M, Mouraux D, et al. Objective evaluation of elbow flexion strength and fatigability after nerve transfer in adult traumatic upper brachial plexus injuries. *Hand Surg*. 2014;19:335–341.
35. Sedain G, Sharma MS, Sharma BS, et al. Outcome after delayed Oberlin transfer in brachial plexus injury. *Neurosurgery*. 2011;69:822–827; discussion 827.
36. Nath RK, Lyons AB, Bietz G. Physiological and clinical advantages of median nerve fascicle transfer to the musculocutaneous nerve following brachial plexus root avulsion injury. *J Neurosurg*. 2006;105:830–834.
37. Liverneaux PA, Diaz LC, Beaulieu JY, et al. Preliminary results of double nerve transfer to restore elbow flexion in upper type brachial plexus palsies. *Plast Reconstr Surg*. 2006;117:915–919.
38. Kokkalis ZT, Bavelou A, Papanikos E, et al. Reconstruction of elbow flexion with a modified Oberlin procedure: a comparative study. *Injury*. 2019;50:S71–S76.
39. Ren GH, Li RG, Xiang DY, et al. Reconstruction of shoulder abduction by multiple nerve fascicle transfer through posterior approach. *Injury*. 2013;44:492–497.
40. De Rezende MR, Rabelo NTA, Júnior CCS, et al. Results of ulnar nerve neurotization to biceps brachii muscle in brachial plexus injury. *Acta Ortop Bras*. 2012;20:317–323.
41. Goubier JN, Teboul F. Rhomboid nerve transfer to the suprascapular nerve for shoulder reanimation in brachial plexus palsy: a clinical report. *Hand Surg Rehabil*. 2016;35:363–366.
42. Johnsen PH, Wolfe SW. Successful nerve transfers for traumatic brachial plexus palsy in a septuagenarian: a case report. *Hand (N Y)*. 2016;11:NP30–NP33.
43. Bhandari PS, Sadhotra LP, Bhargava P, et al. Surgical outcomes following nerve transfers in upper brachial plexus injuries. *Indian J Plast Surg*. 2009;42:150–160.
44. Naito K, Facca S, Lequint T, et al. The Oberlin procedure for restoration of elbow flexion with the da Vinci robot: four cases. *Plast Reconstr Surg*. 2012;129:707–711.
45. Shahriar-Kamrani R, Jafari SM, Guiti MR. The results of using a part of ulnar nerve for restoration of elbow flexion in patients with upper brachial plexus injury. *Acta Med Iran*. 2005;43:204–208.
46. Teboul F, Kakkar R, Ameur N, et al. Transfer of fascicles from the ulnar nerve to the nerve to the biceps in the treatment of upper brachial plexus palsy. *J Bone Joint Surg Am*. 2004;86:1485–1490.

47. Socolovsky M, Martins RS, Di Masi G, et al. Upper brachial plexus injuries: grafts vs. ulnar fascicle transfer to restore biceps muscle function. *Neurosurgery*. 2012;71:ons227–ons232.
48. Suzuki O, Sunagawa T, Yokota K, et al. Use of quantitative intra-operative electrodiagnosis during partial ulnar nerve transfer to restore elbow flexion. *J Bone Joint Surg Br*. 2011;93:364–369.
49. Illmann CF, Doherty C, Wheelock M, et al. The impact of the COVID-19 pandemic on breast reconstruction: a Canadian perspective. *Plast Surg (Oakv)*. 2021;29:287–293.
50. Chapman KM, Berger MJ, Doherty C, et al. Recommendations for patients with complex nerve injuries during the COVID-19 pandemic. *Can J Neurol Sci*. 2021;48:50–55.
51. Sneiders D, Bulstra LF, Hundepool CA, et al. Outcomes of single versus double fascicular nerve transfers for restoration of elbow flexion in patients with brachial plexus injuries: a systematic review and meta-analysis. *Plast Reconstr Surg*. 2019;144:155–166.
52. Brown PW. Factors influencing the success of the surgical repair of peripheral nerves. *Surg Clin North Am*. 1972;52:1137–1155.
53. He B, Zhu Z, Zhu Q, et al. Factors predicting sensory and motor recovery after the repair of upper limb peripheral nerve injuries. *Neural Regen Res*. 2014;9:661–672.
54. Carlsen BT, Kircher MF, Spinner RJ, et al. Comparison of single versus double nerve transfers for elbow flexion after brachial plexus injury. *Plast Reconstr Surg*. 2011;127:269–276.
55. Dupépé EB, Davis M, Elsayed GA, et al. Inter-rater reliability of the modified Medical Research Council Scale in patients with chronic incomplete spinal cord injury. *J Neurosurg Spine*. 2019;30:515–519.
56. Ahmed-Labib M, Golan JD, Jacques L. Functional outcome of brachial plexus reconstruction after trauma. *Neurosurgery*. 2007;61:1016–22; discussion 1022.