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Original Research

The Outcome of Single Versus Double Nerve Transfers in Shoulder Reconstruction of Upper and Extended Upper-Type Brachial Plexus Injuries

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Purpose: The objective of this study was to compare the outcomes of a single nerve transfer (SNT) with double nerve transfer (DNT) in the restoration of shoulder function in patients with upper (C5-6) or extended upper-type (C567) brachial plexus injuries.
Methods: A retrospective review of patients with C5-6 or C567 brachial plexus injuries operated on with nerve transfers from January 1, 2005, to December 31, 2017, was completed. The outcomes between SNT and DNT groups were evaluated with the Filipino Version of the Disabilities of the Arm, Shoulder, and Hand (FIL-DASH) scores, pain scores, muscle strength recovery, and range of motion. A subgroup analysis on surgical delay (< or ≥ 6 months), diagnosis (C5-6 or C567), and length of follow-up (< or ≥ 24 months) was also performed. All statistical significance was set at $P < .05$.
Results: A total of 22 patients with SNT and 29 with DNT were included in this study. There was no significant difference between the SNT and DNT groups as to postoperative FIL-DASH scores, pain, recovery of ≥M4, and range of motion for shoulder abduction and external rotation, although the absolute values for shoulder function were greater in the DNT than the SNT group. There was no significant difference between the SNT and DNT groups for surgical delay, diagnosis, and length of follow-up. A stronger recovery of ≥M4 for external rotation was observed in the DNT group compared to the SNT group if nerve transfer was performed in less than 6 months (86% vs 41%).
Conclusions: The outcomes for shoulder function between the 2 groups were similar, although the DNT group performed slightly better, especially with external rotation. Patients operated on less than 6 months from injury will benefit more from DNT for shoulder function, especially for external rotation.
Clinical relevance: Double nerve transfer may result in improved shoulder function.

Brachial plexus injuries are uncommon, showing a prevalence of 1.2% in a multitrauma study.[1] Motorcycle accidents remain the most common cause of injury, especially in developing countries.[2,3] Involvement of the C5-6 roots with variable inclusion of the C7 root can result in deficits in shoulder abduction and external rotation, elbow flexion, and forearm supination with variable weakness of the elbow, wrist, and finger extensors.[3,4] In upper-type brachial plexus injuries, the sole transfer of a spinal accessory nerve, ie, single nerve transfer (SNT), has been shown to be an effective donor to the suprascapular nerve to regain shoulder abduction and external rotation. External rotation in shoulder abduction recovery has been reported in several studies to range from 55º to 93º and 16º to 86º.[5–9]

Leechavangvongs et al[10,11] reported using a triceps branch of the radial nerve to the axillary nerve via a posterior approach as a second nerve transfer to the shoulder after the spinal accessory nerve to the suprascapular nerve. Several authors have reported increased shoulder function after double nerve transfer (DNT) with the intercostal nerve[12] and median or ulnar nerve[13] as nerve donors and the axillary nerve as the target nerve.[12–21] Cardenas et al [19] in their study in 2008 reported that the more nerves transferred, the

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higher the abduction range in restoring shoulder function. Similar studies comparing SNT with DNT reported a greater shoulder range of motion (ROM) or a higher recovery rate of ≥M4 for shoulder function with DNT.[20,21] One systematic review[22] showed a higher functional recovery in the DNT group compared to the SNT for shoulder function. Few studies directly compared SNT with DNT for shoulder function, and there is still no consensus on which nerve transfer is ideal for restoring shoulder function.

The purpose of this study was to determine the outcomes of single versus double nerve transfers with the Filipino Version of the Disabilities of the Arm, Shoulder, and Hand (FIL-DASH) scores, pain scores, muscle strength, and ROM for shoulder abduction and external rotation in patients with upper (C5-6) and extended upper-type (C567) brachial plexus injuries.

Materials and Methods

A retrospective chart review was completed on the Microsurgery Unit database for patients with C5-6 and C567 type brachial plexus injuries. The inclusion criteria were adult patients with unilateral brachial plexus injuries with C5-6 or C567 involvement, who had a primary nerve transfer procedure to restore shoulder function from January 1, 2005, to December 31, 2017, and a minimum follow-up time of 12 months. Patients with other surgeries to regain shoulder function and whose target nerves were other than suprascapular or axillary nerves were excluded. The protocol was approved by the Research Ethics Board of the authors' institution.

Single and double nerve transfer

Included patients were divided into 2 treatment groups: SNT and DNT. The nerve transfers used to reconstruct the shoulder function were transferred to the suprascapular nerve (SNT) or with an additional transfer to the axillary nerve (DNT). The superior or superior and deep branches of the axillary nerve were the targeted recipient nerves.

Assessment of outcomes

Functional outcomes were measured using the FIL-DASH[23] questionnaire before and after surgery. Muscle strength was measured according to the British Medical Research Council grading system (M0 to M5). Shoulder abduction strength was measured as the angle between the axis of the arm and the axis of the spine. External rotation of the shoulder was measured from full internal rotation (forearm over the abdomen) with the elbow flexing at 90º. Measurements for ROM were performed with a standard goniometer. Preoperative and postoperative pain was measured using the visual analog scale for pain ranging from 0 to 10.[24]

Surgical technique

Surgical exploration was mainly performed via a supraclavicular approach and limited to the upper and middle trunks. The decision to perform nerve transfer was made once the nerve root was determined as avulsed or ungraftable. Preoperative assessment of root avulsion was evaluated with an MRI, EMG-nerve conduction velocity, and clinical examination. A preoperative assessment of root avulsion was considered if there was a pseudomeningocele on the MRI, a normal nerve conduction velocity and no response on the EMG for the anesthetic limb, an elevated hemidiaphragm on the ipsilateral side of chest x-ray, and the presence of scapular winging. These were confirmed during the operation. Avulsed roots were described as pale-looking that felt empty on palpation. If a neuroma was present, internal neurolysis was performed, and the nerve roots were transected proximally until normal-looking fascicles were identified. Otherwise, a nerve transfer was performed. The choice of the donor nerve was based on its availability during preoperative clinical testing, EMG-nerve conduction velocity results, and intraoperative nerve stimulation. Intraoperative muscle-evoked and somatosensory-evoked potential monitoring were not used because the machine was unavailable in the hospital. We used a portable intraoperative nerve stimulator to identify donor nerves for nerve transfers, where the lowest setting (10 mA) was used. An operating microscope was used on all nerve repairs. The other nerve transfers performed were for the restoration of elbow flexion.

After surgery, patients wore a soft neck collar and arm sling for 4 weeks. By the end of the 4th week, passive range of motion was commenced, and patients were advised to perform passive ROM for the shoulder and to try to actively abduct the shoulder while in a supine position using backward shoulder shrugs.

A subgroup analysis was performed for each treatment group based on surgical delay (<6 vs ≥6 months), diagnosis (C5-6 vs C567), and duration of follow-up (12–23 vs ≥24 months) to determine the results of muscle recovery to ≥M4 and a mean ROM for shoulder abduction and external rotation.

Statistical analysis

Descriptive statistics for categorical data were calculated using frequencies and proportions (percentages) and the means and 95% confidence intervals for continuous data. The differences between groups were calculated using the one-tailed Fisher exact test for categorical data. The comparison between means for continuous data used the Kruskal-Wallis test for nonparametric data. The significance level was set at $P < .05$ for all analyses.

Results

A total of 51 patients were included in the study. The donor nerve for the 22 SNT patients comprised the spinal accessory nerve in 21 patients and the phrenic nerve in one patient. We used the phrenic nerve for the latter patient because the spinal accessory nerve was weak clinically and during intraoperative nerve stimulation. The patient also had no preoperative hemidiaphragm elevation or rib injuries at the implicated site. The suprascapular nerve was the recipient nerve. In the DNT group, the donor nerves included the intercostal nerves (3rd to 5th) in 2 patients, the nerve to the lateral head of the triceps in 4 patients, and the nerve to the long head of the triceps in 23 patients. The baseline characteristics for the 2 groups are summarized in Table 1.

Filipino Version of the Disabilities of the Arm, Shoulder, and Hand score

In both SNT and DNT groups, the mean preoperative and postoperative FIL-DASH scores were 51.7 (n = 26; 95% CI: 41.9–61.4) and 34.8 (n = 33; 95% CI: 29.3–40.3), respectively, which differed significantly ($P < .05$). We observed a significant difference in 20 patients with preoperative (56.3; 95% CI: 44.8–67.7) and postoperative FIL-DASH scores (35.8; 95% CI: 29.9–41.7) ($P = .001$).

In the DNT group, 14 patients had both preoperative and postoperative FIL-DASH scores, which differed significantly ($P = .008$). In the SNT group, only 6 patients had both preoperative and postoperative FIL-DASH scores, which were also significantly different ($P = .04$). A summary of the preoperative and postoperative unpaired FIL-DASH scores for SNT and DNT is shown in Table 2. The postoperative FIL-DASH scores were not significantly different between the SNT (34.6) and DNT (34.9) groups ($P = .5$).

Table 1
Demographic Data on 51 Patients With Single Versus Double Nerve Transfers for Shoulder Reconstruction

Demographic Data	SNT (n = 22)	DNT (n = 29)	*P* value*
Mean age (y, SD, 95% CI)	28.6, 8.7, 24.8–32.5	29.5, 7.2, 27.1–32.8	.5
Mean surgical delay (mo, SD, 95% CI)	6.9, 3.8, 5.3–8.6	7.7, 2.9, 6.6–8.8.	.6
Mean follow-up (mo, SD, 95% CI)	47, 31, 33–61	34, 25, 25–44	.1
Mean preoperative FIL-DASH (Score, SD, 95% CI)	49.4, 26.9, 30.1–68.7 (n = 10)	53.1, 23, 40.7–65.3. (n = 16)	.5
Mean postoperative FIL-DASH (Score, SD, 95% CI)	34.6, 17.2, 23.7–45.6 (n = 12)	34.9, 14.8, 28.2–41.7 (n = 21)	.5
Mean preoperative VAS for pain (SD, 95% CI)	5.1, 3.6, 3.4–6.9 (n = 18)	3.0, 3.1, 1.7–4.2 (n = 28)	.05
Mean postoperative VAS for pain (SD, 95% CI)	2.8, 3.0, 1.2–4.3 (n = 17)	1.5, 2.1, 0.7–2.4 (n = 28)	.2

* Kruskal-Wallis test (significance at *P* < .05). 95% CI, 95% confidence interval.

Table 2
FIL-DASH Scores in Single Versus Double Nerve Transfers

Scores	Single Nerve Mean, SD	95% CI	Double Nerve Mean, SD	95% CI	*P* Value*
Preoperative FIL-DASH	49.4, 26.9 (n = 10)	30.2–68.7	53.1, 23.0 (n = 16)	40.7–65.3	.5
Postoperative FIL-DASH	34.6, 17.6 (n = 12)	23.7–45.6	34.9, 14.8 (n = 21)	28.2–41.7	.5
Mean Difference					
FIL-DASH	14.8	-4.9–34.6	18.1	5.4–30.8	
P value	.1		.01		

* Rank sum test (significance at *P* < .05).

Pain score

In 45 patients with preoperative and postoperative visual analog scale pain scores, the pain score significantly decreased from 3.7 (95% CI: 2.7–4.7) to 2.0 (95% CI: 1.2–2.8) (*P* = .0001) for both groups. In the SNT group with both preoperative and postoperative scores (n = 17), there was a significant decrease in pain (*P* = .01) from the preoperative (4.8; 95% CI: 3.0–6.6) to postoperative score (2.8; 95% CI: 1.2–4.3). In the DNT group, there was also a significant decrease in the pain score (*P* = .003) for 28 patients from 3.0 (95% CI: 1.8–4.2) to 1.5 (95% CI: 1.0–2.4). The pain score data are summarized in Table 1.

Functional outcomes

Muscle strength and range of motion

There was no significant difference between the SNT and the DNT groups for mean muscle strength recovery and ROM for shoulder function (*P* > .05). However, recovery to ≥M3 and ROM tended to be greater in the DNT group for both shoulder abduction and external rotation. A summary of the functional outcomes is shown in Table 3.

Outcomes of muscle recovery and range of motion on surgical delay, diagnosis, and follow-up

The 2 treatment groups were analyzed for surgical delay, diagnosis, and length of follow-up. The key findings showed that for both SNT and DNT groups, no significant differences were identified in the ≥M4 muscle recovery and ROM for shoulder abduction and external rotation, except in the DNT group where 86% recovered to ≥M4 external rotation in those patients with a surgical delay of fewer than 6 months compared to 41% operated on later. However, we observed a trend where muscle strength recovery and ROM were greater in patients with a surgical delay of fewer than 6 months, who had C5-6 injuries, and those with longer follow-ups (≥24 months) for shoulder function in both treatment groups. Tables 4 and 5 summarize the recovery of muscle strength to ≥M4 and ROM in shoulder abduction and external rotation between the SNT and DNT groups, respectively.

Complications

Complications included a postoperative hematoma in one patient with a posterior approach to the spinal accessory nerve transfer. This was managed nonoperatively, and the outcome for this patient was satisfactory (DNT: 60º shoulder abduction/M4; 90º external rotation/M3 at 12 months follow-up). In patients using a branch of the radial nerve for transfer or the spinal accessory nerve, no postoperative weakness in elbow extension or shoulder shrug was experienced. In the single patient with a phrenic nerve transfer, there were no respiratory complaints during the immediate postoperative course. Immediate postoperative chest x-ray only showed an elevated hemidiaphragm. Clinically, there was no difficulty breathing, even at 36 months follow-up. Three patients had complications related to DNT for elbow flexion. Two patients had ulnar nerve paresthesia that resolved within 3 months. One had a weakness of the flexor carpi radialis (M3) but recovered to M4 within 8 months. There were no intra or postoperative complications in the one patient where the phrenic nerve was used as the donor nerve.

Discussion

Restoring shoulder function remains the second priority (after elbow flexion) in managing patients with brachial plexus injuries. Although shoulder abduction has been frequently reported in most studies on brachial plexus reconstruction of the shoulder, external rotation plays a critical role in the functional capacity of the shoulder. Balzer et al[25] considered a clinically useful shoulder external rotation to be -35º (relative to the neutral position), with at least ≥M2 strength, which is sufficient to allow the arm to be away from the body for active elbow flexion.

FIL-DASH score

The improvement in the FIL-DASH score for the SNT group did not reach statistical significance. Although the FIL-DASH score did not show statistical improvement after surgery in the SNT group, the mean difference of 14.8 points may represent the minimally

Table 3
Functional Outcomes of Single Versus Double Nerve Transfer for Shoulder Function

Shoulder Function	Single Nerve (n = 22)	Double Nerve (n = 29)	*P* Value
Shoulder abduction			
Mean MMT, SD	3.7, 0.8	3.8, 0.6	1.0*
95% CI	3.4–4.0	3.3–3.9	
≥M3 (%)	20/22 (91)	29/29 (100)	.6†
≥M4 (%)	15/22 (68)	20/29 (69)	.2†
Mean ROM			
Degrees, SD	97, 53	99, 52	.8*
95% CI	74–120	79–119	
Shoulder external rotation			
Mean MMT, SD	3.1, 1.1	3.4, 0.8	.3*
95% CI	2.6–3.6	3.1–3.7	
≥M3 (%)	19/22 (86)	27/29 (93)	.4†
≥M4 (%)	8/22 (36)	15/29 (52)	.2†
Mean ROM			
Degrees, SD	58, 40	69, 35	.5*
95% CI	40–76	55–82	

* Kruskal-Wallis test (significance at $P < .05$).
† One-tailed Fisher exact test (significance at $P < .05$). 95% CI, 95% confidence interval; MMT, manual muscle testing.

Table 4
Single and Double Nerve Transfer for Muscle Recovery (≥M4) in Terms of Surgical Delay, Diagnosis, and Follow-up

Single Nerve Transfer (n = 22)			
Factor		Shoulder Abduction	Shoulder External Rotation
Surgical delay			
n = 11	<6 mo	64% (7/11)	45% (5/11)
n = 11	≥6 mo	73% (8/11)	27% (3/11)
	P value*	.5	.3
Diagnosis			
n = 4	C56	100% (4/4)	50% (2/4)
n = 18	C567	61% (11/18)	33% (6/18)
	P value	.2	.5
Follow-up			
n = 5	12–23 mo	60% (3/5)	20% (1/5)
n = 17	≥24 mo	71% (12/17)	41% (7/17)
	P value	.5	.4
Double Nerve Transfer (n = 29)			
Surgical Delay			
n = 7	<6 mo	71% (5/7)	86% (6/7)
n = 22	≥6 mo	68% (15/22)	41% (9/22)
	P value	.6	.049
Diagnosis			
n = 19	C56	63% (12/19)	42% (8/19)
n = 10	C567	80% (8/10)	70% (7/10)
	P value	.3	.2
Follow-up			
n = 12	12–23 mo	58% (7/11)	42% (5/12)
n = 17	≥24 mo	76% (13/17)	59% (10/17)
	P value	.3	.3

* One-tailed Fisher exact test (significance at $P < .05$).

clinically important difference (MCID) of the DASH score and may indicate moderate improvement. The MCID for the DASH score was reported by Franchignoni et al,[26] and an MCID of at least 10.83 points may indicate moderate improvement, which serves as the lower boundary for the MCID.

Muscle strength and range of motion

There was no significant difference in mean muscle strength recovery and ROM between SNT and DNT. However, absolute values were greater for the DNT group. Similar findings were also reported by several authors where a DNT resulted in a greater ROM for shoulder abduction.[19–21]

Several case series on SNTs in patients with C5-6 brachial plexus injuries showed that recovery to ≥M4 strength for shoulder abduction ranged from 20% to 88.9%[6,7] with a mean ROM ranging from 55.5° to 77.1° across various studies.[5,6,8] However, the recovery of shoulder external rotation was not as promising in these studies. In the SNT group, the mean recovery to ≥M4 across studies was only 20%, with a mean ROM ranging from 44.3° to 86°.[6,9] The results in this study were similar to findings reported in literature, where 68% regained strength ≥M4 with a mean of 97° for shoulder abduction, and 36% of patients (8/22) recovered to ≥M4 with a mean ROM of 58° for external rotation in the SNT group.

In studies that investigated DNT procedures, the mean recovery of ≥M4 shoulder abduction ranged from 30% to 88.9%,[10,13–15,18] and the mean ROM ranged from 92° to 115°.[11–17] The mean recovery of ≥M4 external rotation ranged from 20% to 60%, with a mean ROM ranging from 54° to 136°.[11–17] In this case series, the results of the DNT for shoulder abduction were similar to published literature,

Table 5
Single and Double Nerve Transfer for Range of Motion in Terms of Surgical Delay, Diagnosis, and Follow-up

Single Nerve Transfer (n = 22)			
Factor		Shoulder Abduction	Shoulder External Rotation
Surgical delay			
n = 11	<6 mo	104, 53 (68–140)	64, 46 (33–95)
n = 11	≥6 mo	90, 54 (54–126)	51, 34 (29–75)
	P value*	.6	.6
Diagnosis			
n = 4	C56	116, 54 (30–202)	60, 25 (20–99)
n = 18	C567	93, 53 (66–119)	57, 43 (36–79)
	P value	.5	.7
Follow-up			
n = 5	12–23 mo	62, 28 (28–96)	39, 7 (31, 47)
n = 17	≥24 mo	107, 54 (79–135)	63, 44 (40–86)
	P value	.1	.2
Double Nerve Transfer (n = 29)			
Surgical delay			
n = 7	<6 mo	102, 54 (52–152)	80, 22 (59–101)
n = 22	≥6 mo	98, 54 (74–122)	65, 38 (48–82)
	P value	1.0	.5
Diagnosis			
n = 19	C56	98, 60 (69 – 126)	66, 35 (50–83)
n = 10	C567	102, 39 (73 – 130)	73, 36 (47–99)
	P value	.5	.6
Follow-up			
n = 12	12–23 mo	86, 52 (53–119)	59, 39 (34–84)
n = 17	≥24 mo	108, 53 (81–135)	75, 31 (59–92)
	P value	.1	.4

* Kruskal-Wallis Test (significant at $P < .05$).

reaching a mean of 99° with 69% of patients experiencing recovery ≥M4 and a mean of 69° of external rotation with 52% of patients having ≥M4 recovery.

Several studies directly compared SNT and DNT for shoulder function in patients with traumatic brachial plexus injuries.[19–21] For example, Cardenas-Mejia et al[19] concluded that the triple nerve transfer group had the highest shoulder abduction compared to double and SNT, but this was only observed in 4 patients, and the transfers included distal targets like divisions and C5 nerve root. In 2013, we compared the results of SNT and DNT for shoulder function in 20 patients.[20] The DNT group had a higher ≥M4 recovery rate (80% and 40%) and greater ROM (123° and 86°) for shoulder abduction and external rotation compared to SNT.[20] Texakalidis et al[21] reported that in 14 patients, those with DNT had a higher ROM (90°) than SNT (42.5°) for shoulder abduction. However, patients in the DNT group were mainly upper-type injuries, while those in the SNT group had C5-T1 root involvement. This difference between groups may have affected the results. In these comparative studies, the absolute values for shoulder function were consistently greater in the DNT group even though they did not reach statistical significance. In a pooled analysis review by Garg et al,[22] the DNT group had a higher ≥M4 recovery rate and greater ROM for shoulder abduction and external rotation.

Chu et al[12] reported in their DNT series that patients with longer than 24 months of follow-up and a surgical delay of <3 months had a significantly greater ROM for shoulder abduction but not for external rotation. They also reported a significantly greater ROM for shoulder abduction and external rotation for patients in the ≤30-year-old age group. The study by Cardenas-Mejia et al[19] also had a minimum follow-up of 3 years, which may have contributed to the good results of shoulder function. The findings in this study were in agreement with those of Chu et al[12] and Cardenas-Mejia et al,[19] where patients with ≥24 months follow-up had a greater ROM and recovery strength ≥M4 for both shoulder abduction and external rotation.

Tsai et al[18] reported higher peak isometric strength scores for patients with C5-6 injuries compared to C567 injuries after DNT. However, this difference was not significant. A similar finding was reported by Suzuki et al,[8] which noted that the shoulder abduction was 97.5° in C5-6 injuries compared to 72.5° in C567 injuries. Our findings are consistent with these previous reports, in which we observed a higher percentage of C5-6 injuries recovering to ≥M4 and a greater ROM for both shoulder abduction and external rotation after SNT, although the differences were not statistically significant. Interestingly in the DNT group, the C567 injuries had a higher ≥M4 recovery and ROM for both shoulder functions, although the difference was not significant. A possible reason for this might be the low sample size used in the analysis. Other factors, like potential longer surgical delays or shorter follow-ups in the C567 group, might also explain this outcome.

In terms of surgical delay, a recent systematic review by Martin et al[27] investigated the timing of surgery in traumatic brachial plexus injuries. The authors concluded that the ideal timing of the operative intervention is <6 months after injury. Klein[28] reported that ~40% of C5-6 lesions recover to useful function and that this rate decreases to 15% if it is a C567 lesion. In a similar review by Hems,[29] the author believes that a delay of 2–3 months may be warranted, especially if there are no indications for early exploration (<2 weeks). In this case series, patients with a surgical delay of <6 months had slightly higher rates of recovery to ≥M4 for shoulder abduction in the DNT group but a larger difference in external rotation, especially in the DNT group ($P = .05$). The results in this study confirm previous findings in most literature, such that a higher ROM for shoulder function was observed in patients with a surgical delay of fewer than 6 months.

Some authors suggest transferring the superficial radial nerve to the ulnovolar part of the median nerve to relieve the pain in C5-6 avulsion injuries.[30,31] In this study, no surgery was performed to address the pain except reconstructive surgery. Our results showed that in both treatment groups, there was a reduction in the pain score postoperative compared to preoperative, but this was only significant in the DNT group. However, there was no significant difference in the postoperative visual analog scale scores between the 2 treatment groups.

One of the advantages of this study was the use of a comparator group (DNT) and the homogeneity of the donor and recipient nerves. The donor nerve for the SNT was the spinal accessory nerve (21/22, and one phrenic nerve), and the recipient nerves were all suprascapular nerves (22/22). In the DNT group, all spinal accessory nerves (donor nerves) were repaired/transferred to the suprascapular nerve (recipient nerve). For the second nerve transfer, all recipient nerves were the axillary nerves, and most of the donor nerves were from the nerve to the long head of the triceps (23/29). Two patients had intercostal nerves as donors, and 4 had the branch to the lateral head of the triceps as a donor.

The retrospective nature of this study was a limitation, as well as the inadequate number of patients. This may have been the reason why statistical significance was not achieved. In addition, most patients did not have both preoperative and postoperative FIL-DASH scores, making analysis challenging and prone to bias. The Medical Research Council scale was usually reported when measuring muscle strength, but a more objective tool is still needed. Using peak isometric strength by Tsai et al[18] and EMG might offer a more objective assessment of muscle strength and recovery.

Conclusions

Patients with upper or extended upper-type brachial plexus injuries can benefit from both SNT and DNT for shoulder reconstruction. Recovery to ≥M4 and ROM for shoulder function tend to favor DNT over SNT, but the difference was not significant. The ROM and recovery to ≥M4 for shoulder function were similar for surgical delay, diagnosis, and length of follow-up for both SNT and DNT groups. Patients with a surgical delay of <6 months, C5-6 injuries, and a follow-up of ≥24 months tend to have a higher percentage of ≥M4 recovery and a greater ROM for shoulder abduction and external rotation. A marginal significance was observed in the DNT group, where patients tended to recover ≥M4 external rotation strength when the surgical delay was <6 months.

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