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ORIGINAL ARTICLE

Long-Term Outcomes of Nerve Transfers in Adult Patients with C5–C7 and C5–C8 Brachial Plexus Injuries

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ABSTRACT

Background. Nerve reconstructions for C5 to C8 brachial plexus injuries are challenging due to the extent of injury and paucity of nerve donors.

Objective. The objective of this paper was to determine the long-term clinical outcomes of nerve transfers for shoulder and elbow function in patients with C5–C7 or C5–C8 brachial plexus injuries.

Methodology. We retrospectively reviewed the charts of all patients with C5–C7 or C5–C8 brachial plexus injuries treated with nerve transfers from January 1, 2005, to December 31, 2022, with at least 24 months follow-up. Filipino Version of the Disability of the Arm, Shoulder and Hand (FIL-DASH) scores, range of motion (ROM), and muscle strength were compared between single and double nerve transfers, and between early (within six months of injury) and delayed (more than six months) surgery.

Results. A total of 21 patients with a mean age of 29.9 years old were included. The mean surgical delay was 6.4 ± 3.0 months, while the mean follow-up was 58.5 ± 29.7 months. There were 11 patients with C5–C7 injuries, and 10 patients with C5–C8 injuries. FIL-DASH scores were available for eight patients, with a mean postoperative improvement of 25 points. There were no significant differences between single (SNT) and double nerve transfers (DNT) in terms of elbow flexion and shoulder function. Early surgery (within six months of injury) resulted in higher mean shoulder abduction range (110° vs 51°) compared to delayed surgery (more than six months).

Conclusion. Good elbow flexion and shoulder abduction recovery can be expected in nerve transfers for patients with C5–C7 or C5–C8 brachial plexus injuries. A higher ROM for shoulder abduction can be expected if surgery is done within six months of injury.

Keywords. nerve transfer, nerve reconstruction, extended upper type brachial plexus, long-term outcomes, brachial plexus injuries

INTRODUCTION

Upper type brachial plexus injuries account for approximately 25% to 30% of all brachial plexus injuries, with 14% of these injuries involving the C5 to C7 nerve roots.[1,2] Patients with involvement of the middle trunk and parts of the lower trunk of the brachial plexus lose the ability to control shoulder abduction and external rotation, elbow flexion and extension, and to some degree, wrist and finger extension.[2] However, Bertelli and Ghizoni reported in 2013 that loss of control of triceps, wrist, and finger extension likely involves the C8 nerve root, since injuries involving purely the C5 to C7 nerve roots tend to spare the triceps, wrist and finger extensors. Patients with decreased grasp, and wrist and elbow extension may also have an additional C8 injury.[3]

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Nerve transfers for shoulder abduction and external rotation result in fair to good outcomes, with most patients reporting improved shoulder stability and patient reported outcomes.[3–7] Brachial plexus injuries involving the C5 to C8 nerve roots limit options for nerve transfers, especially for the shoulder and elbow. In contrast, those with only C5 to C6 injuries have better outcomes in terms of muscle recovery of the elbow and shoulder.[8–10]

The objective of this study was to present the results of nerve transfers for the restoration of shoulder and elbow function in patients with C5–C7 or C5–C8 nerve injuries.

METHODOLOGY

This was a retrospective study that reviewed patient charts to determine the clinical outcomes of patients with C5–C7 or C5–C8 nerve root injuries treated at a single Microsurgery Unit from January 1, 2005 to December 31, 2022. The data were collected from the unit's database. Included were all adult patients aged ≥ 18 years with a diagnosis of C5–C7 or C5–C8 injury who underwent primary nerve transfer surgery for the restoration of shoulder and elbow function, with a minimum follow-up of 24 months. Excluded were patients with bilateral injuries, complete C5–T1 injuries, primary nerve repair, severe joint contractures, and disorders that would otherwise affect the clinical evaluation of brachial plexus recovery.

The diagnosis of C5–C7 nerve root injury was made based on paralysis or weakness (≤ M3) of the flexor carpi radialis with or without reduced function of the pronator teres, triceps, or latissimus dorsi. The diagnosis of C5–8 injuries was based on weakness of the triceps, wrist extensors, with or without weakness of finger extension.

The protocol was approved by the ethics review board of the authors' institution.

Outcomes measurement

Outcomes were measured using the following: disability score using the Filipino Version of the Disability of the Arm, Shoulder and Hand (FIL-DASH) score, manual muscle testing using the British Medical Research Council (BMRC) grading system of M0–M5, range of motion (ROM) in degrees, and pain using the visual analog scale. The shoulder's range of motion and muscle strength were tested in abduction and external rotation (from full internal rotation, with elbow flexed and forearm parallel to the abdomen), and the elbow in flexion and extension. Recovery for elbow extension was considered when the BMRC grade was ≥ M3. The final measurements were considered on their latest follow-up.

Outcomes were compared between single nerve transfers (SNT) and double nerve transfers (DNT), and early (within six months) and delayed surgery (six months or later).

Operative procedures

Nerve transfer procedures included those that reconstructed shoulder and elbow function. Target recipient nerves were the suprascapular nerve (SSN) and/or the axillary nerve (AXN) for the shoulder and biceps, and/or the brachialis branch of the musculocutaneous nerve (MCN) for the elbow. Donor nerves to the musculocutaneous were the intercostal nerve and the medial pectoral nerve. The most commonly used nerve donors were the ulnar and/or median nerve for elbow flexion, and the partial radial nerve to the axillary nerve. Additional tendon or nerve transfers were also done as needed to restore wrist, finger or thumb extension.

Statistical analysis

The statistical testing software used was STATA Version 14.0 (Stata Corp. LLC, College Station, Texas, USA). Descriptive statistics used were frequencies and proportions for categorical data. Measures of central tendency used were means with their corresponding standard deviations and/or 95% confidence intervals, and medians with their interquartile range for continuous variables. Means were compared using the Kruskall-Wallis test for nonparametric data and Fisher's exact test for categorical data. The level of significance for all statistical tests was set at $p < 0.05$.

RESULTS

A total of 21 patients were included (Table 1). The mean surgical delay was 6.4 ± 3.0 months, while the mean follow-up was 58.5 ± 29.7 months. There were 11 patients with C5–7 injuries and 10 patients with C5–8 injuries.

Outcome Measures

FIL-DASH scores

Both pre- and postoperative FIL-DASH scores were available in eight patients. In these patients, there was a significant improvement in the FIL-DASH score with a mean difference of 25 (95% CI: 10, 40), (p-value < 0.05, Table 2).

Functional outcomes

Table 3 shows the outcomes of nerve transfers on the restoration of elbow and shoulder function. In two cases, the MCN was selected as a direct target nerve (donors: intercostal nerves and medial pectoral nerves). Both patients had M4 elbow flexion strength and 140° of flexion.

The overall results for the remaining 19 patients with either single or double nerve transfer showed that strong elbow flexion of ≥ M4 was achieved in 16 of 19 patients (84%) with a mean ROM of 131°. Double nerve transfers for elbow and shoulder function had greater muscle strength, higher chances of achieving ≥ M4 strength, and greater ROM for elbow flexion, but the difference did not achieve statistical significance ($p > 0.05$).

Table 1. Demographic Characteristics (*n* = 21)

	Mean (SD) [a]	Median (IQR) [b]	95% CI [c]	*N* (%)
Age, years	29.9 (8.5)	28 (24, 34)	26.1, 33.8	35.8 ± 9.97
Sex				
Male				19 (90.5)
Female				2 (9.5)
Surgical delay (months)	6.4 (3.0)	5.4 (4.7, 6.7)	5.1, 7.8	
FIL-DASH [d]				
Pre-operative (*n* = 8)	59.5 (21.5)	63.3 (63.3, 75.8)	41.6, 77.5	
Post-operative (*n* = 16)	34.0 (18.4)	30 (24.2, 50)	24.2, 43.8	
Pain Score (VAS) [e]				
Pre-operative (*n* = 21)	3.6, 3.6	3.0 (0, 6)	2.0, 5.2	
Post-operative (*n* = 21)	2.6 (2.9)	2.0 (0, 5)	1.3, 3.9	
Follow-up (months)	58.5 (29.7)	54.7 (35, 84)	45.0, 71.2	
Nerve Procedures				
Shoulder				
Single [f]				16 (71)
Double [g]				5 (29)
Elbow				
Single				6 (28)
Double				13 (62)
ICN-MCN [h]				1 (5)
MPN-MCN [i]				1 (5)

a) SD – Standard Deviation; b) IQR – Interquartile range; c) CI – Confidence interval; d) FIL-DASH – Filipino Disability of the Arm, Shoulder and Hand; e) VAS – Visual analog scale; f) Single nerve transfer: Shoulder (spinal accessory nerve to the suprascapular nerve); Elbow (ulnar nerve fascicle to biceps branch [Oberlin procedure] or median nerve fascicle to biceps branch; g) Double nerve transfer: Shoulder (spinal accessory nerve to suprascapular nerve + triceps branch to the axillary nerve); Elbow (single nerve transfer [ulnar nerve] + median nerve fascicle to brachialis branch; h) ICN- MCN - intercostal nerves to musculocutaneous nerve, i) MPN-MCN; medial pectoral nerve to musculocutaneous nerve.

Table 2. Results of pre and post-operative FIL-DASH scores (*n* = 8)

FIL-DASH [a] Score	Mean (SD) [b]	95% CI [c]	*p*-value [d]
Pre-operative	59.5 (21.5)	41.6, 77.5	
Post-operative	34.5 (15.6)	21.4, 47.6	
Difference	25 (18)	10, 40	0.006

[a] FIL-DASH – Filipino Disability of the Arm, Shoulder and Hand; [b] SD – Standard deviation; [c] CI – Confidence interval; [d] Paired t-test, significant at $p < 0.05$.

There was no significant difference in shoulder and elbow strength recovery between those who underwent nerve transfer within six months and six months or later post-injury. However, those who underwent earlier surgery (within six months) recovered more shoulder abduction ROM (110° vs 51°, $p = 0.01$). A mean shoulder abduction of 85° and mean external rotation of 67° was achieved for all transfers to the shoulder (Tables 3 and 4).

In the 21 patients, elbow extension was present at the time of surgery with least M4 in three patients. Spontaneous recovery during the follow-up period of at least M3 elbow extension was observed in six patients (≥ M4 in five). Nerve transfer for elbow extension was done for one patient using the intercostal nerve, with only M2 recovery. The rest ($n = 11$) had no recovery and no reconstruction of the triceps muscle.

Postoperative FIL-DASH scores were available in 16 patients. Overall, the postop FIL-DASH scores were better for those with elbow extension ($n = 8$) with a mean score of 26 compared to those with no elbow extension ($n = 8$) with a mean score of 43 ($p = 0.048$). Elbow extension was present in seven of the 11 patients with C5–C7 injuries, and in only one of nine patients in the C5–C8 group.

Pain scores

There was no significant difference in the pain scores in all patients before and after nerve transfers (3.6 vs. 2.6; $p = 0.1$).

DISCUSSION

In patients with C5–C7 or C5–C8 injuries, nerve transfers can restore elbow flexion, and shoulder abduction and external rotation. Among patients with C5–C7 injuries, 64-67% of patients regain ≥ M4 elbow flexion strength following biceps reinnervation.[6–10] In terms of shoulder function, Chu et al.[11] reported dual nerve transfers in 19 patients (16 with C5–C7 injuries) achieving 94° shoulder abduction and 54° external rotation in the long-term. Patients who received surgery within three months post-injury, were younger, and had longer follow-ups and had greater shoulder function. In 2022, Bertelli and Ghizoni[12] reported that in 52 patients with C5–8 brachial plexus injuries, 81% recovered ≥ M4 strength full elbow flexion, and 88% recovered a median shoulder abduction of 80° and external rotation of 120°.

Double nerve transfer in extended injuries is controversial because of the possibility of transferring injured or recovering fascicles from donor nerves. An animal study on elbow flexion in rat models has shown that partial C8 injuries may still benefit from DNT, especially when no other donors are available. Lower trunk injuries with 25% and 75% intact fascicles had similar function at both donor and recipient sites when assessed with the grooming test, muscle mass, retro-

Table 3. Outcomes for elbow and shoulder function in patients by type of transfer (*n* = 21)

	Type of transfer		*p*-value
Elbow flexion [a]	**Single (*n* = 6)**	**Double (*n* = 13)**	
Mean MMT (95% CI)	3.7 (2.1, 5.2)	4.0 (3.9, 4.0)	0.5 [b]
≥ M4 (%)	4 of 6 (67%)	12 of 13 (92%)	0.2 [c]
Mean ROM (°), 95% CI	129 (108, 149)	131 (121, 142)	0.5 [b]
Combined ROM (°), 95% CI	131 (122, 139)		
Postop FIL-DASH (mean, 95% CI)	43.2 (24.7, 61.7) (*n* = 6)	26.4 (13.3, 39.5)	0.06 [b]
Shoulder function abduction	**Single (*n* = 16)**	**Double (*n* = 5)**	
Mean MMT (95% CI)	3.3 (2.4, 4.1)	3.8 (3.2, 4.4)	0.6
≥ M4 (%)	8 of 16 (50%)	4 of 5 (80%)	0.2
Mean ROM (°), 95% CI	78 (50, 106)	106 (66, 146)	0.3
Combined ROM (°), 95% CI	85 (62, 107)		
External rotation			
Mean MMT (95% CI)	2.9 (2.0, 3.7)	3.5 (2.9, 3.7)	0.6
≥ M4 (%)	7 of 16 (44%)	2 of 5 (40%)	0.7
Mean ROM (°), 95% CI	64.2 (37.0, 91)	75 (23, 126)	0.8
Combined ROM (°), 95% CI	66.7 (44.8, 88.4)		
Postop FIL-DASH (mean, 95% CI)	35.8 (23.2, 48.3) (*n* = 11)	30.1 (6.4, 53.9) (*n* = 5)	0.5

[a] Donor nerves intercostal and medial pectoral nerves were excluded (*n* = 2); [b] Kruskal-Wallis test; [c] Fisher's Exact test, 1-sided

Table 4. Outcomes for elbow and shoulder function by surgical delay (*n* = 21)

	Surgical delay		*p*-value
Elbow flexion [a]	**< 6 months (*n* = 12)**	**≥ 6 months (*n* = 9)**	
Mean MMT (95% CI)	3.8 (3.2, 4.4)	3.9 (3.5, 4.4)	0.6 [b]
≥ M4 (%)	11 of 12 (92%)	7 of 9 (78%)	0.3 [c]
Mean ROM (°), 95% CI	126 (99, 152) [d]	125 (110, 139)	0.2 [b]
Combined ROM (°), 95% CI	132 (123, 139)		
Postop FIL-DASH (mean, 95% CI)	43.2 (24.7, 61.7) (*n* = 6)	26.4 (13.3, 39.5)	0.06 [b]
Shoulder function abduction	**< 6 months (*n* = 12)**	**≥ 6 months (*n* = 9)**	
Mean MMT (95% CI)	3.8 (2.4, 4.1)	2.7 (3.2, 4.4)	0.2
≥ M4 (%)	8 of 12 (67%)	4 of 9 (44%)	0.3
Mean ROM (°), 95% CI	110 (50, 106)	51 (66, 146)	0.01
Combined ROM (°), 95% CI	85 (62, 107)		
External rotation			
Mean MMT (95% CI)	3.1 (2.0, 3.7)	2.9 (2.9, 3.7)	0.4
≥ M4 (%)	6 of 12 (50%)	3 of 9 (33%)	0.4
Mean ROM (°), 95% CI	77 (37.0, 91)	53 (23, 126)	0.3
Combined ROM (°), 95% CI	66.7 (44.8, 88.4)		
Postop FIL-DASH (mean, 95% CI)	35.8 (23.2, 48.3) (*n* = 11)	30.1 (6.4, 53.9) (*n* = 5)	0.2 [b]

[a] Donor nerves intercostal and medial pectoral nerves were included (*n* = 2); [b] Kruskal-Wallis test; [c] Fisher's Exact test, 1-sided; [d] Only 1 of 12 patients had failed elbow flexion recovery

grade neuron labelling of regenerated axons and immunohistochemical staining of regenerated axons.[13] In 2023, Chang et al.[14] using double fascicular transfers, achieved ≥ M4 elbow flexion strength for patients with C5–C7 (73%) and C5–C8 (71.9%) acute brachial plexus injuries. This study concluded that double fascicular transfers can achieve good elbow flexion recovery in partial upper-type brachial plexus injuries.

For shoulder function, two other studies[5,11] showed similarly good results with shoulder abduction (73–81°) and external rotation (43–69°). Our results were similar, achieving ≥ M4 strength of elbow flexion with a mean range of 132° in 84% of patients, shoulder abduction of 85° in 57% of patients, and shoulder external rotation of 67° in 56% of patients.

There is still controversy whether single or double nerve transfers are better for restoring elbow function. Some studies have shown similar results[5,15,16] while other reported the superiority of double nerve transfers.[6,17] In this study, double nerve transfers showed superior results compared to single transfers in achieving M4 muscle strength, both for elbow and shoulder function; however, this difference did not reach statistical significance. The additional nerve transfer for the shoulder (triceps branch to axillary nerve) provided additional strength for shoulder abduction, but a moderate effect on external rotation. Double nerve transfers result in greater motor strength and shoulder abduction range compared to single nerve transfers as reported by other authors.[18–20]

Few donor nerves are available for the shoulder in patients with C5–C7 or C5–C8 injuries. The triceps branch of the radial nerve is usually not available or too weak in dual nerve reinnervation of the shoulder. In such cases, augmentation can be done using a nerve graft where a proximal nerve stump is available. The distal C5 root or the posterior or anterior division of the upper trunk can be used, depending on which deficit is to be restored. However, in our setting, we are unable to document the presence of nerve root avulsion, since we don't have intraoperative monitoring (such as spinal evoked potential), or MRIs. Presently, our institution's surgeons rely on inspecting the nerve for normal-looking fascicles after sectioning, or stimulating the long thoracic nerve to determine viability of the root.[21]

Early surgical intervention, whether for nerve grafting or transfer, has been recommended by many authors.[5,8,11,22] In this study, the surgical delay was not a factor in nerve transfers for elbow flexion and shoulder function, as most were done within 12 months of the injury. More patients in the group receiving early surgery (within six months) achieved ≥ M4 strength of elbow flexion, and shoulder abduction and external rotation, but this difference did not reach statistical significance. Early surgery did, however, yield better ROMs for shoulder abduction (Table 4).

In terms of DASH scores, Liu et al.[23] reported significant improvements following nerve transfers using the phrenic nerve (DASH score improved from 90.1 to 66.8) and partial ulnar nerve (88.1 to 57.4). Similarly, Dolan et al.[24] reported that those treated early (within six months) with nerve transfers had better DASH scores compared to those treated late (62.1 vs. 76.3). Carlsen et al. also reported significant post-operative improvement in DASH scores using either single or double nerve transfers.[15]

Among the limitations of the study were the retrospective nature and the small sample size. Although the minimum follow-up was 24 months, a longer follow-up may show continued improvement in terms of strength and ROM. Also, some authors showed that reinnervated biceps and brachialis muscles fatigue early.[25] These outcomes may be included in future assessments of these patients.

CONCLUSION

In summary, good elbow flexion and shoulder function and improved FIL-DASH scores can be achieved after surgery for patients with C5–C7 or C5–C8 brachial plexus injuries. Double nerve transfers and early surgery (within six months) resulted in better elbow flexion range and shoulder strength ≥ M4), but these differences did not reach statistical significance. A significantly higher shoulder abduction range can be expected with early surgery.

STATEMENT OF AUTHORSHIP

All authors certified fulfillment of ICMJE authorship criteria.

CREDIT AUTHOR STATEMENT

EPE: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing – review and editing, Visualization, Supervision, Project administration, Funding acquisition; **EFDD:** Software, Validation, Investigation, Data Curation, Writing – original draft preparation, Writing - review and editing, Project administration.

DATA AVAILABILITY STATEMENT

The datasets generated and analyzed in this study are included in the published article.

AUTHOR DISCLOSURE

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REFERENCES

1. Narakas AO, Hentz VR. Neurotization in brachial plexus injuries. Indication and results. Clin Orthop Relat Res. 1988;(237):43–56. PMID: 3056647
2. Suroto H, Antoni I, Siyo A, et al. Traumatic brachial plexus injury in Indonesia: an experience from a developing country. J Reconstr Microsurg. 2022;38(7):511–23. PMID: 34470060 PMCID: PMC9470278 DOI: 10.1055/s-0041-1735507
3. Bertelli JA, Ghizoni MF. Clinical findings in C5-C6 and C5-C7 root palsies with brachial plexus traction lesions. J Hand Surg Eur Vol. 2013;38(3):237–41. PMID: 23242315 DOI: 10.1177/1753193412471009
4. Venkatramani H, Bhardwaj P, Faruquee SR, Sabapathy SR. Functional outcome of nerve transfer for restoration of shoulder and elbow function in upper brachial plexus injury. J Brachial Plex Peripher Nerve Inj. 2008;3:15. PMID: 18505571 PMCID: PMC2432056 DOI: 10.1186/1749-7221-3-15
5. Hems T. Re: Dolan RT, Butler JS, Murphy SM, Hynes D, Cronin KJ. Health-related quality of life and functional outcomes following nerve transfers for traumatic upper brachial plexus injuries. J Hand Surg Eur. 2012, 37: 642-51. J Hand Surg Eur Vol. 2013;38(2):217. PMID: 23386192 DOI: 10.1177/1753193412472105
6. Donnelly MR, Rezzadeh KT, Vieira D, Daar D, Hacquebord J. 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(3):361–9. PMID: 31755577 DOI: 10.1002/micr.30536
7. Haldane C, Frost G, Ogalo E, Bristol S, Doherty C, Berger M. A systematic review and meta-analysis of patient-reported outcomes following nerve transfer surgery for brachial plexus injury. PM R. 2022;14(11):1368–81. PMID: 35100499 DOI: 10.1002/pmrj.12778
8. Ayhan E, Soldado F, Fontecha CG, Bertelli JA, Leblebicioglu G. Elbow flexion reconstruction with nerve transfer or grafting in patients with brachial plexus injuries: a systematic review and comparison study. Microsurgery. 2020;40(1):79–86. PMID: 30761593 DOI: 10.1002/micr.30440
9. Sungpet A, Suphachatwong C, Kawinwonggowit V, Patradul A. Transfer of a single fascicle from the ulnar nerve to the biceps muscle after avulsions of upper roots of the brachial plexus. J Hand Surg Br. 2000;25(4):325–8. PMID: 11057997 DOI: 10.1054/jhsb.2000.0367

10. 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: nonrandomized prospective study of 23 consecutive patients. Microsurgery. 2014; 34(7):511–5. PMID: 24753064 DOI: 10.1002/micr.22263
11. Chu B, Wang H, Chen L, Gu Y, Hu S. Dual nerve transfers for restoration of shoulder function after brachial plexus avulsion injury. Ann Plast Surg. 2016;76(6):668–73. PMID: 26835823 DOI: 10.1097/SAP.0000000000000747
12. Bertelli JA, Ghizoni MF. Reconstruction of C5-C8 (T1 hand) brachial plexus paralysis in a series of 52 patients. J Hand Surg Am. 2022;47(3):237–46. PMID: 35012795 DOI: 10.1016/j.jhsa.2021.11.014
13. Chang TN, Shafarenko M, Dadouch R, et al. Can a partially injured donor nerve restore elbow flexion in an acute brachial plexus injury in rats? Plast Reconstr Surg. 2019;144(5):1105–14. PMID: 31441804 DOI: 10.1097/PRS.0000000000006149
14. Chang TN, Lu JC, Lee CH, et al. Double fascicular transfer using partially injured donor nerves: is it powerful enough to restore elbow flexion in acute brachial plexus injuries? J Reconstr Microsurg. 2023;39(4):272–8. PMID: 34666407 DOI: 10.1055/s-0041-1736320
15. Carlsen BT, Kircher MF, Spinner RJ, Bishop AT, Shin AY. Comparison of single versus double nerve transfers for elbow flexion after brachial plexus injury. Plast Reconstr Surg. 2011;127(1):269–76. PMID: 20871484 DOI: 10.1097/PRS.0b013e3181f95be7
16. Martins RS, Siqueira MG, Heise CO, Foroni L, Teixeira MJ. A prospective study comparing single and double fascicular transfer to restore elbow flexion after brachial plexus injury. Neurosurgery. 2013;72(5):709–14. PMID: 23313985 DOI: 10.1227/NEU.0b013e318285c3f6
17. Srampickal GM, Mathew A, Raveendran S, Yadav BK, Thomas BP. Restoration of elbow flexion in adult traumatic brachial plexus injury - a quantitative analysis of results of single versus double nerve transfer. Injury. 2021;52(3):511–5. PMID: 33755551 DOI: 10.1016/j.injury.2020.10.090
18. Texakalidis P, Tora MS, Lamanna JJ, Wetzel J, Boulis NM. combined radial to axillary and spinal accessory nerve (SAN) to suprascapular nerve (SSN) transfers may confer superior shoulder abduction compared with single SA to SSN transfer. World Neurosurg. 2019; 126:e1251–6. PMID: 30898759 DOI: 10.1016/j.wneu.2019.03.075
19. Kostas-Agnantis I, Korompilias A, Vekris M, et al. Shoulder abduction and external rotation restoration with nerve transfer. Injury. 2013;44(3):299–304. PMID: 23337704 DOI: 10.1016/j.injury.2013.01.005
20. Cardenas-Mejia A, O'Boyle CP, Chen KT, Chuang DC. Evaluation of single-, double-, and triple-nerve transfers for shoulder abduction in 90 patients with supraclavicular brachial plexus injury. Plast Reconstr Surg. 2008;122(5):1470–8. PMID: 18971731 DOI: 10.1097/PRS.0b013e3181881fc5
21. Flores LP. Functional assessment of C-5 ventral rootlets by intraoperative electrical stimulation of the supraclavicular segment of the long thoracic nerve during brachial plexus surgery. J Neurosurg. 2008;108(3):533–40. PMID: 18312101 DOI: 10.3171/JNS/2008/108/3/0533
22. Sneiders D, Bulstra LF, Hundepool CA, Treling WJ, Hovius SER, Shin AY. 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(1):155–66. PMID: 31246823 DOI: 10.1097/PRS.0000000000005720
23. Liu Y, Zhuang Y, Yu H, Xiong H, Lao J. 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(9):1245–51. PMID: 29980455 DOI: 10.1016/j.bjps.2018.05.024
24. Dolan RT, Butler JS, Murphy SM, Hynes D, Cronin KJ. Health-related quality of life and functional outcomes following nerve transfers for traumatic upper brachial plexus injuries. J Hand Surg Eur Vol. 2012;37(7):642–51. PMID: 22178751 DOI: 10.1177/1753193411432706
25. Wilcox M, Brown H, Johnson K, Sinisi M, Quick TJ. An assessment of fatigability following nerve transfer to reinnervate elbow flexor muscles. Bone Joint J. 2019;101-B(7):867–71. PMID: 31256676 DOI: 10.1302/0301-620X.101B7.BJJ-2019-0005.R1