ORIGINAL ARTICLE

Bali Medical Journal (*Bali MedJ*) 2022, Volume 11, Number 2: 879-884
P-ISSN.2089-1180, E-ISSN: 2302-2914

Early external neurolysis surgery reduces the pain and improves the functional outcomes and quality of life among traumatic brachial plexus injury patients

Azmi Farhadi[1,2], Lydia Arfianti[3,4], Heri Suroto[1,2*]

[1]Department of Orthopedic and Traumatology, Faculty of Medicine, Universitas Airlangga, Surabaya, 60132, Indonesia;
[2]Department of Orthopedic and Traumatology, Dr. Soetomo Hospital, Surabaya, 60132, Indonesia;
[3]Department of Physical Medicine and Rehabilitation, Faculty of Medicine, Universitas Airlangga, Surabaya, 60132, Indonesia;
[4]Department of Physical Medicine and Rehabilitation, Dr. Soetomo Hospital, Surabaya, 60132, Indonesia;

*Corresponding author:
Heri Suroto;
Department of Orthopedic and Traumatology, Faculty of Medicine, Universitas Airlangga, Surabaya, 60132, Indonesia;
heri-suroto@fk.unair.ac.id

Received: 2022-05-27
Accepted: 2022-07-05
Published: 2022-08-16

ABSTRACT

Introduction: Traumatic brachial plexus injury (TBPI) is a debilitating and devastating injury that significantly impacts individuals' quality of life. This study aimed to evaluate the functional outcomes, pain improvement and quality of life after external neurolysis surgery in TBPI patients.

Methods: A retrospective study was conducted at Dr Soetomo Hospital in Surabaya, Indonesia. Data of TBPI patients who were operated with external neurolysis surgery from 2003 to 2020 were collected. The functional outcome was measured using disabilities of the arm, shoulder, and hand (DASH) score, the pain assessment with pain visual analog score (VAS) and the quality of life with 36-item short-form (SF-36). The outcomes were also compared between those who had the surgery less or more than 6 months after the injury.

Results: A total of 493 TBPI patients were diagnosed between 2003 to 2020. Out of total, 37 patients had external neurolysis surgery, mean age of 31±12.5 years, were included in the analysis. External neurolysis surgery in TBPI patients improved all DASH, VAS and SF-36 scores and these improvements were likely influenced by sex, age, occupation, affected side and the level of the injury. In addition, our data also suggested that the patients who had external neurolysis surgery before 6 months had better outcomes than those after 6 months after the injury in term of DASH, VAS and SF-36 scores.

Conclusion: In TBPI cases, earlier external neurolysis surgery could result in better pain reduction, functional outcome and quality of life outcomes.

Keywords: Brachial plexus injury, TBPI, external neurolysis, functional outcome, DASH score.
Cite This Article: Farhadi, A., Arfianti, L., Suroto, H. 2022. Early external neurolysis surgery reduces the pain and improves the functional outcomes and quality of life among traumatic brachial plexus injury patients. *Bali Medical Journal* 11(2): 879-884. DOI: 10.15562/bmj.v11i2.3510

INTRODUCTION

Traumatic brachial plexus injury (TBPI) is one of the most debilitating and devastating injuries.[1-3] Although TBPI is not a life-threatening injury, lifelong severe disability can be difficult to reverse and could have a significant impact on functional impairment and the quality of life (QOL).[2-4] TBPI usually occurs at a productive age and the majority is caused by high-speed motorcycle accidents (76.1%).[3] The trauma can also be caused by low energy trauma such as blunt trauma and shoulder dislocation (7%) and manifested as impairment of the upper extremity's motor and/or sensory, which is sometimes resolved spontaneously with rehabilitation.[2,5,6]

The old approach of TBPI management in the 1990s was watchful waiting for 5-6 months before surgery is indicated. The reason is to give a time of at least three months for the nerve to heal spontaneously as is explained by Wallerian degeneration theory.[4,7,8] The problem with watchful waiting is that the longer the injury is not treated, the more muscle fibers lose the innervation. The distal part will commonly start to degenerate four months after the injury, which may result in muscle fibrosis and reduce the chance of any clinical recovery.[8,9] On the contrary, those who prefer earlier treatment would argue that, by performing external neurolysis, earlier treatment would relieve the plexus from the nerve injury (compression) and result in faster recovery and faster axonal regrowth.[3,7,9,10] This controversy over the optimal timing of surgery motivate this study to evaluate and compare the functional outcomes after performing external neurolysis at a different time in TBPI. The aim of this study was to determine the role of timing of surgery on the functional outcomes of TBPI cases.

METHODS

Study design

A cohort-retrospective study was conducted at Dr Soetomo Hospital in Surabaya, Indonesia. Data were collected using questionnaires and physical examinations starting from 2003 to 2020.

Study subjects

Patients aged at least 17 years old at the time of surgery, underwent external neurolysis ≤ 12 months after the time of the accident, had a follow-up time of ≤ 6 months after surgery, performed surgery

by the same surgeon were considered eligible in this study. Those patients with signs of preganglionic and avulsion root injury: signs of Horner's syndrome (the triad of pupil miosis, eyelid ptosis, and facial anhidrosis), winged scapula (C5-C7), parascapular muscle atrophy (C5), or hemidiaphragm paralysis confirmed with chest radiograph (C3-C5) were excluded. In addition, patients who had brachial plexus injury due to obstetrical brachial plexus palsy (OBPP), brachial plexus injury caused by congenital disorders, suffered from polyneuropathy, and those with organic brain lesions were also excluded in this study.

When there was a missing data, the patients were contacted. If the patient cannot be reached then patient is excluded. Type of occupation refers to the last one month before the injury. The affected site was the most affected extremity of the patient. The causative of TBPI and associated injuries of TBPI were also assessed.

Study variables

The response variables of the study: functional, pain and quality of life. Those variables were measured using disabilities of the arm, shoulder, and hand (DASH) score, visual pain analog (VAS) score and 36-item short-form (SF-36) score, respectively.[11-13] All of the variables were measured before and after the external neurolysis. The lower score of DASH and VAS indicates better condition while a higher score of SF-36 indicates the better quality of life.

Some plausible explanatory variables such as basic demographic characteristics such as gender, age, occupation and smoking status were collected. In addition, affected side and the level of lesion were also assessed.

Statistical analysis

Normality distribution was tested by Shapiro Wilk tests. Independent Student's t-test and analysis of variance (ANOVA) were used to compare the scores of DASH, VAS and SF-36 between or among groups. The p-value of <0.05 was considered significant and all analyses were conducted using SPSS 26.0.

RESULTS

Patients' characteristics

A total of 493 patients were diagnosed with TBPI between 2003 to 2020 and 40 were elected for external neurolysis surgery. In total, 37 patients met the study criteria (Figure 1). The mean age of the samples was 31±12.5 years. The most common cause of TBPI was motor vehicle accidents (n=30; 81%) while the least common was related to sports injuries (n=1; 3%) (Figure 2A). The associated injuries of TBPI including related to clavicle fracture (n=3; 8%), humeral fracture (n=3; 8%), femoral fracture (n=2; 5% and shoulder dislocation (n=1; 3%) (Figure 2B). Most of the TBPI (76%) had no associated injury.

DASH, VAS and SF-36 scores pre- and post-external neurolysis surgery

We divided the samples into two groups based on the time between the injury incident and the external neurolysis surgery (i.e., before 6 and after 6 months). The characteristics of patients with TBPI who had the external neurolysis surgery before and after 6 months are presented in Table 1.

Factors associated with improvement of DASH, VAS and SF-36 score post-external neurolysis

We assessed the associations of some variables on improvement of DASH, VAS and SF-36 scores after and before the

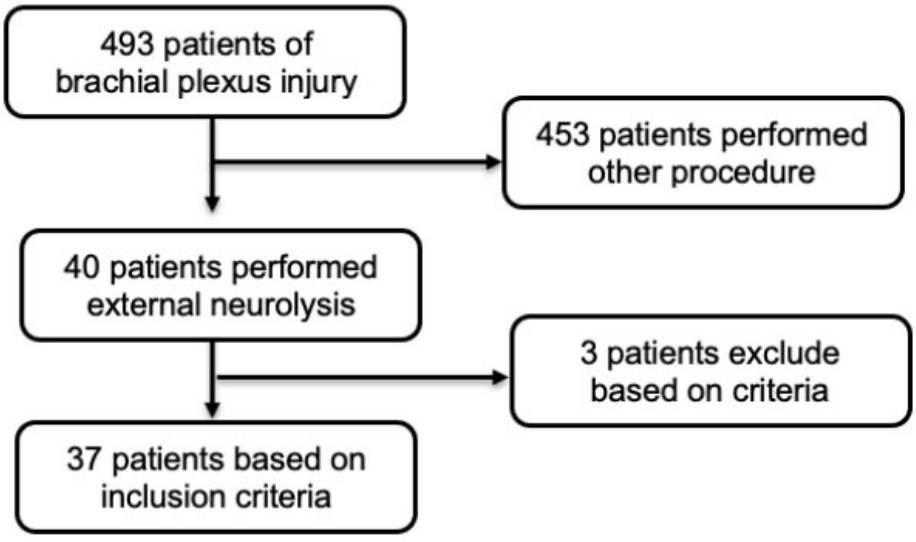

Figure 1. Sample selection flow chart.

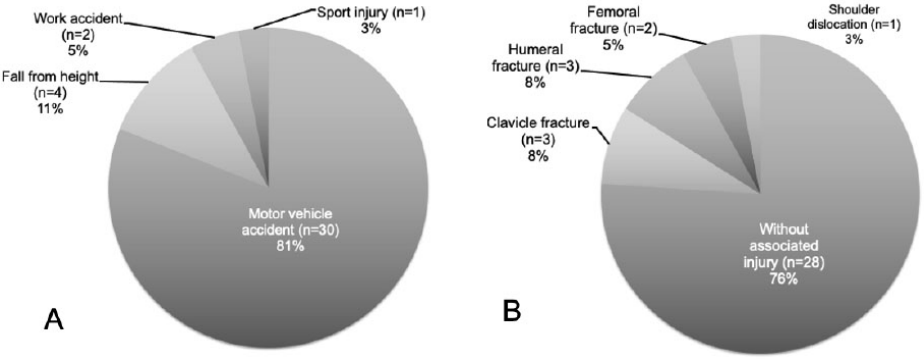

Figure 2. The causes of traumatic brachial plexus injury (A) and associated injuries related to traumatic brachial plexus injury (B).

Table 1. **Demographic data and distribution of DASH, VAS and SF-36 scores pre- and post-external neurolysis of patients.**

Variable	Group (month)	n (%)	DASH score		VAS score		SF-36 score	
			Pre-external neurolysis	Post-external neurolysis	Pre-external neurolysis	Post-external neurolysis	Pre-external neurolysis	Post-external neurolysis
Sex								
Male	< 6	11 (30)	51.7±10.93	28.35±14.31	6.98±1.6	1.63±0.96	68.08±8.75	89.97±9.12
	≥ 6	16 (43)	55.1±17.33	23.36±11.07	7.63±0.72	1.91±1.22	73.89±6.95	93.31±6.75
Female	< 6	4 (11)	45.08±12.89	29.5±7.19	7.5±1.0	2.25±1.89	73.85±9.41	82.53±2.36
	≥ 6	6 (16)	53.5±11.48	24.12±15.68	8±0.63	1.67±0.52	72.47±12.3	86.22±7.80
Age (years)								
Adolescent (17-19)	< 6	1 (3)	35±0.00	24±0.00	6±0.00	2±0.00	84±0.00	91.3±0.00
	≥ 6	10 (27)	44.17±12.48	28.58±11.64	6.83±0.75	1.83±0.41	77.83±4.89	84.18±5.00
Young adult (19-40)	< 6	9 (24)	54.29±13.03	30.7±13.97	7.11±0.93	2±1.50	69.14±9.82	86.57±9.57
	≥ 6	6 (16)	47.5±9.71	21.65±12.77	7.9±0.74	1.9±0.99	73.37±10.65	90.45±7.73
Middle adult (41-65)	< 6	5 (14)	59.3±19.71	25.92±11.69	7.65±2.35	2±1.41	67.6±5.64	93.48±2.05
	≥ 6	6 (16)	59.62±8.53	21.73±11.98	7.98±0.52	1±0.63	69.38±5.18	94.77±4.37
Occupation								
Employee	< 6	1 (3)	53.28±12.69	20.3±2.5	7.57±1.9	2±1.41	69.39±8.77	90.44±6.68
	≥ 6	6 (16)	50.59±18.34	24.7±11.51	7.63±0.52	1.33±0.52	72.4±4.3	93±7.44
Students	< 6	3 (8)	62±11.20	22.5±8.30	6±0.78	1.5±0.54	73.3±3.54	80±5.20
	≥ 6	1 (3)	46±0.00	29±0.00	6±0.00	1±0.00	79±0.00	85±0.00
Housewife	< 6	8 (22)	66.17±12.45	30.67±8.33	7.67±1.15	1.67±2.08	70.8±8.77	91.57±1.68
	≥ 6	6 (16)	38±11.10	22.5±16.28	8±0.78	1±1.20	61.6±10.21	79.8±7.20
Entrepreneur	< 6	3 (8)	58.88±16.64	35.63±17.50	7.25±0.96	1.75±0.96	73.23±7.97	91.25±1.27
	≥ 6	9 (24)	51.39±11.10	22.07±16.28	7.89±0.78	1.78±1.2	72.32±10.11	91.7±7.34
Smoking status								
Non-smoking	< 6	10 (27)	52.87±16.17	34.78±12.50	6.8±1.69	1.4±0.70	68.43±8.07	80.15±9.25
	≥ 6	6 (16)	47.67±11.15	21.21±12.10	7.39±0.7	1.56±0.63	75.19±8.78	82.58±7.95
Smoking	< 6	5 (14)	58.28±15.45	30.42±13.94	7.4±0.89	2.2±1.64	68±11.18	91.26±5.17
	≥ 6	16 (43)	55.83±11.47	29.83±10.48	7.83±0.75	1.83±1.33	67±5.76	90.83±5.40
Affected side								
Right	< 6	10 (27)	54.94±14.35	28.76±11.85	7.1±0.99	2.4±1.51	72.97±8.33	91.04±4.40
	≥ 6	15 (40)	52.15±11.04	26.14±11.90	7.67±0.72	1.67±0.82	73.65±8.46	82.69±7.36
Left	< 6	5 (14)	54.14±19.68	28.46±15.35	6.8±2.28	1.2±0.45	62.92±6.47	85.48±12.56
	≥ 6	7 (19)	45.07±12.02	18.04±11.36	7.86±0.69	1.57±0.98	73.17±9.01	92.41±7.53
Level of lesion								

Variable	Group (month)	n (%)	DASH score		VAS score		SF-36 score	
			Pre-external neurolysis	Post-external neurolysis	Pre-external neurolysis	Post-external neurolysis	Pre-external neurolysis	Post-external neurolysis
C5	< 6	1 (3)	35±0.00	24±0.00	6±0.00	2±0.00	84±0.00	91.3±0.00
	≥ 6	1 (3)	57±0.00	45.5±0.00	9±0.00	4±0.00	68.3±0.00	83.3±0.00
C5 and C6	< 6	2 (5)	43.2±0.00	18.8±0.00	6±0.00	2±0.00	64.4±0.00	82.5±0.00
	≥ 6	8 (22)	50.56±12.05	22.55±15.00	7.5±0.76	1.38±0.74	72.81±8.34	87.44±7.5
C5, C6, and C7	< 6	2 (5)	50.3±22.11	18±0.00	6±2.65	2±1.73	73.93±3.49	95.5±2.21
	≥ 6	4 (10)	49.88±15.42	21.58±15.74	8.25±0.5	1.5±0.58	75.73±9.11	93.43±4.57
C7, C8, and Th1	< 6	2 (5)	58±17.68	27±1.41	7.7±1.41	1±0.00	72±15.56	94.45±1.34
	≥ 6	1 (3)	45±0.00	28±0.00	8±0.00	3±0.00	79.1±0.00	88.8±0.00
C5-Th1	< 6	8 (22)	59.38±13.84	34.89±14.28	7.85±1.04	2.25±1.58	66.26±8.2	86.08±9.22
	≥ 6	8 (22)	49.84±11.27	22.28±4.93	7.98±0.53	1.5±0.53	73.03±9.78	91.61±8.25

external neurolysis surgery among total samples (Table 2). Sex, age, occupation and level of lesion were associated with the changes of DASH ($p<0.05$). The DASH score was not related significantly to the affected by the side of injury ($p=0.935$). Our data indicated that the improvement of VAS score influenced by sex, age, job, affected side, and lesion level ($p<0.05$). Improvement of SF-36 score was related to sex, age, job, affected side, and lesion level ($p<0.05$).

The role of time of surgery on improvement of DASH, VAS and SF-36 scores

Our data indicated that the DASH, VAS and SF-36 scores improved significantly after the surgery in both <6 month (early group) or ≥6-month group (late group) (Table 3). In early and late group, the mean DASH scores reduced from 54.67 to 28.66 ($p=0.011$) and from 49.9 to 23.56 ($p=0.001$), respectively (Table 3). Our data also indicated that the VAS scores reduced significantly after the surgery both groups. In early group, the mean VAS scores reduced from 7.00 to 2.00 ($p=0.010$) while in late group the VAS scores declined from 7.73 to 1.64 ($p=0.001$). For SF-36, the mean scores improved (increased) in both early group (from 69.62 to 89.19; $p=0.023$) and late group (from 73.50 to 89.92; $p=0.011$) (Table 3).

DISCUSSION

Management of TBPI is quite challenging due to the unavailability of proper guidelines or consensus.[3,7,8] Current management focused on supportive management, rehabilitation effort, and surgery.[7,14,15] Unfortunately, losing the ability for optimal movement or even paralysis in TBPI patients have significant impacts on the quality of life and psycho-socio-economic aspects that may lead to post-traumatic stress disorder, major depression, anxiety, suicide attempt and psychotic disorders.[3,16]

There are several factors to be considered which would affect functional prognosis in TBPI patients after surgery.[3,7,11] The functional prognosis can be determined based on the nature of the plexus injury (e.g. level of injury, mechanism injury, and initial pain), presence of associated injuries, surgical expertise, practical operative time constraints, and postoperative rehabilitation.[2,8] These functional parameters are important because it not only affects the patient's function capability but also patient's quality of life and satisfaction.[17]

Clinical outcomes and rehabilitation after surgery External neurolysis is a procedure which aims to release nerve's compression by removing structures directly entrapping and deforming the nerve, allowing physiologic nerve gliding and elongation during extremity movement.[10,18] As the cause of nerve pathology in every patient varied, it is not surprising to observe that early recovery was only seen in isolated muscle groups and not in every patient.[12,19-21]

Evaluating the success of TBPI surgical procedure need to also consider patients' satisfaction and desire to return to work.[1,13,16] A previous study found significant correlation between clinical evaluation and the activities of daily living after the surgery.[22] SF-36 was measured I the present study to specifically assess this aspect. Our study found significantly better SF-36 scores post-surgery on patients who had surgery <6 months compared to ≥6 months. This is in line with a previous study which found a significant improvement of DASH, SF-36, and pain scale scores on patients who had surgery in the first six months after trauma.[11]

Neuropathic pain associated with TBPI can be very severe, persistent, and resistant to treatment. Gradual aggregation of intra-neural and extra-neural scar tissue led to rising nerve dysfunction and worsening of symptoms.[9,15] About 30-37% reduction in pain level was observed when external neurolysis was done on TBPI patients.[15,18] Pain level is also related to the sensory function of the affected side. A study reported the progressive amelioration of sensory function in cases who had earlier external neurolysis surgery and the recovered six to eight weeks after surgery.[10] Sensory recovery is poor by timing, it could be attributed to collateral sprouting of fibers from an overlapping dermatome, through axonal regeneration and cerebral cortex reorganization.[7,9,15]

One of the essential factors determining the nerve procedure's success is the

Table 2. Factor associated with improvement of DASH, VAS, and SF-36 score between pre- and post-surgery.

Variable	n	DASH score difference (Post – Pre)	p-value	VAS score difference (Post – Pre)	p-value	SF-36 score difference (Post – Pre)	p-value
Sex [a]							
Male	27	-27.7±14.33	0.027*	-5.78±1.25	0.045*	21.43±7.66	0.046*
Female	10	-22.18±9.62		-4.9±1.64		12.72±9.34	
Age (years old) [b]							
Adolescent (17-19)	11	-14.92±3.88	0.002*	-4.71±2.14	0.017*	6.48±1.8	0.001*
Young Adults (19-40)	15	-24.78±12.30		-5.63±1.01		17.24±5.68	
Middle Adults (41-65)	11	-35.83±12.76		-6.27±1.01		25.6±4.39	
Occupation [b]							
Employee	14	-29.16±14.66	0.049*	-5.85±1.41	0.044*	20.84±6.61	0.003*
Students	7	-20.2±9.52		-4.5±1.83		7.39±2.77	
Housewife	4	-23±14.218		-6.75±0.96		21.37±8.59	
Entrepreneur	12	-27.45±13.65		-5.62±1.12		18.96±7.20	
Affected side [a]							
Right	25	-26.07±13.21	0.935	-4.56±5.26	0.030*	11.85±5.63	0.030*
Left	12	-26.46±14.13		-5.83±1.59		19.46±7.11	
Level of lesion [b]							
C5	2	-11.25±0.35	0.049*	-5±1.41	0.028*	11.15±5.44	0.490
C5 and C6	10	-26.61±12.11		-4.33±1.66		15±8.98	
C5, C6, and C7	6	-30.01±17.6		-6.43±1.13		19.36±7.15	
C7, C8, and Th1	3	-18±16.71		-6.33±0.58		18.2±12.45	
C5-Th1	16	-22.02±12.16		-6±0.82		19.2±7.60	

*Statistically significant at p<0.05
[a] Analyzed using independent Student's t-test
[b] Analyzed using Anova

Table 3. Comparison of DASH, VAS and SF-36 scores pre- and post-external neurolysis surgery between 6-month group and ≥6-month groups.

Parameter	Time	Pre-surgery Mean ± SD	Post-surgery Mean ± SD	p-value
DASH	<6 months	54.67±15.60	28.66±12.55	0.011*
	≥6 months	49.9±11.57	23.56±12.09	0.001*
VAS	<6 months	7.00±1.46	2.00±1.36	0.010*
	≥6 months	7.73±0.70	1.64±0.85	0.001*
SF-36	<6 months	69.62±8.98	89.19±8.05	0.023*
	≥6 months	73.5±8.42	89.92±7.24	0.011*

*Statistically significant at p<0.05

survival of the involved nerve's proximal stump.[4,9,23] The numbers of apoptosis of nerve's proximal stump on more than six months post-trauma is higher than on less than six months post-trauma.[22,23] This occurs because the expression of tumor necrosis factor-alpha (TNF-α) and Caspase on patients who underwent surgery after six months was higher than before six months.[23] This was the supported by the previous studies.[4,23,24] Studies concluded that the optimal time to surgery on TBPI patients are between 3-6 month.[4,25] Other studies also found that that the TBP patients had better mobility when the surgery conducted earlier than 6 months.[15,25,26] Altogether these are the basics of grouping in the present study.

There are some limitations of this study. The study was conducted from a single hospital and may not represent Indonesia's general population. Other topographic and socioeconomic factors that were not assessed in this study may also have an impact on the outcomes.

CONCLUSION

Our study suggests that external neurolysis surgery in TBPI patients improved all DASH, VAS and SF-36 scores in both groups of patients who had the surgery before or after 6 months of the injury. Our data also highlights that the patients who had external neurolysis surgery before earlier before six months had better outcomes than those after six months.

ETHICAL APPROVAL

The study was conducted according to the Declaration of Helsinki guidelines and the study protocol was approved by the Institutional Review Board of Dr Soetomo Hospital, Surabaya, Indonesia (0236/LOE/301.4.2/XII/2020).

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY

Data available on request to the authors. Kindly contact the corresponding author.

INFORMED CONSENT

Written informed consent was obtained from all participants before the study.

FUNDING/SUPPORT

All authors do not receive any financial support/funding for this study.

ACKNOWLEDGEMENT

The authors would like to thank all the patients who were willing to participate in this study. The authors would also like to thank the staffs at Dr Soetomo Hospital during this study in providing the necessary space for examination, permits, and directions.

REFERENCES

1. Rasulić L, Savić A, Živković B, Vitošević F, Mićović M, Baščarević V, et al. Outcome after brachial plexus injury surgery and impact on quality of life. Acta Neurochir (Wien) [Internet]. 2017;159(7):1257–64. Available from: http://dx.doi.org/10.1007/s00701-017-3205-1.
2. Suroto H, Rahman A. Traumatic brachial plexus injury: proposal of an evaluation functional prognostic scoring system. Br J Neurosurg [Internet]. 2021;1–5. Available from: http://dx.doi.org/10.1080/02688697.2021.1947975
3. Suroto H, Antoni I, Siyo A, et al. Traumatic Brachial Plexus Injury in Indonesia: An Experience from a Developing Country. *J Reconstr Microsurg*. Epub ahead of print 1 September 2021. DOI: 10.1055/s-0041-1735507.
4. Martin E, Senders JT, DiRisio AC, Smith TR, Broekman MLD. Timing of surgery in traumatic brachial plexus injury: a systematic review. J Neurosurg [Internet]. 2019;130(4):1333–45. Available from: http://dx.doi.org/10.3171/2018.1.jns172068
5. Smania N, Berto G, La Marchina E, Melotti C, Midiri A, Roncari L, Zenorini A, Ianes P, Picelli A, Waldner A, Faccioli S, Gandolfi M. Rehabilitation of brachial plexus injuries in adults and children. Eur J Phys Rehabil Med. 2012;48(3):483-506. PMID: 23075907.
6. Gutkowska O, Martynkiewicz J, Urban M, Gosk J. Brachial plexus injury after shoulder dislocation: a literature review. Neurosurg Rev [Internet]. 2018/06/30. 2020 Apr;43(2):407–23. Available from: https://pubmed.ncbi.nlm.nih.gov/29961154
7. Midha R, Grochmal J. Surgery for nerve injury: current and future perspectives. J Neurosurg [Internet]. 2019;130(3):675–85. Available from: http://dx.doi.org/10.3171/2018.11.jns181520
8. Rezende MR de, Silva GB, Paula EJL de, Mattar Junior R, Camargo OP de. What has changed in brachial plexus surgery? Clinics (Sao Paulo) [Internet]. 2013;68(3):411–8. Available from: https://pubmed.ncbi.nlm.nih.gov/23644864
9. Menorca RMG, Fussell TS, Elfar JC. Nerve physiology: mechanisms of injury and recovery. Hand Clin [Internet]. 2013 Aug;29(3):317–30. Available from: https://pubmed.ncbi.nlm.nih.gov/23895713
10. Swartz KR, Boland M, Fee DB. External neurolysis may result in early return of function in some muscle groups following brachial plexus surgery. Clin Neurol Neurosurg [Internet]. 2012;114(6):768–75. Available from: http://dx.doi.org/10.1016/j.clineuro.2011.12.035
11. Aras Y, Aydoseli A, Sabanci PA, Akcakaya MO, Alkir G, Imer M. Functional Outcomes after Treatment of Traumatic Brachial Plexus Injuries: Clinical Study. Turkish J Trauma Emerg Surg [Internet]. 2013;19(6):521–8. Available from: http://dx.doi.org/10.5505/tjtes.2013.48107
12. Aizawa J, Masuda T, Hyodo K, Jinno T, Yagishita K, Nakamaru K, et al. Ranges of active joint motion for the shoulder, elbow, and wrist in healthy adults. Disabil Rehabil [Internet]. 2013;35(16):1342–9. Available from: http://dx.doi.org/10.3109/09638288.2012.731133
13. Kitajima I, Doi K, Hattori Y, Takka S, Estrella E. Evaluation Of Quality Of Life In Brachial Plexus Injury Patients After Reconstructive Surgery. Hand Surg [Internet]. 2006;11(03):103–7. Available from: http://dx.doi.org/10.1142/s0218810406003279
14. Noland SS, Bishop AT, Spinner RJ, Shin AY. Adult Traumatic Brachial Plexus Injuries. J Am Acad Orthop Surg [Internet]. 2019;27(19):705–16. Available from: http://dx.doi.org/10.5435/jaaos-d-18-00433
15. Kato N, Htut M, Taggart M, Carlstedt T, Birch R. The effects of operative delay on the relief of neuropathic pain after injury to the brachial plexus. J Bone Joint Surg Br [Internet]. 2006;88-B(6):756–9. Available from: http://dx.doi.org/10.1302/0301-620x.88b6.16995
16. Suroto H, Putra RA, Karimah A. Relationship between disability and pain to post-traumatic stress disorder, depression, and anxiety in patient with postoperative brachial plexus injury (BPI). Br J Neurosurg [Internet]. 2020;35(3):254–8. Available from: http://dx.doi.org/10.1080/02688697.2020.1784846
17. Ali ZS, Heuer GG, Faught RW, Kaneriya SH, Sheikh UA, Syed IS, Stein SC, Zager EL. Upper brachial plexus injury in adults: comparative effectiveness of different repair techniques. J Neurosurg. 2015;122(1):195-201. doi: 10.3171/2014.9.JNS132823.
18. Morgan R, Elliot I, Banala V, Dy C, Harris B, Ouellette EA. Pain Relief after Surgical Decompression of the Distal Brachial Plexus. J Brachial Plex Peripher Nerve Inj [Internet]. 2020 Oct 16;15(1):e22–32. Available from: https://pubmed.ncbi.nlm.nih.gov/33082844
19. Nath RK, Lyons AB, Bietz G. Microneurolysis and decompression of long thoracic nerve injury are effective in reversing scapular winging: long-term results in 50 cases. BMC Musculoskelet Disord [Internet]. 2007 Mar 7;8:25. Available from: https://pubmed.ncbi.nlm.nih.gov/173437
20. Armas-Salazar A, García-Jerónimo AI, Villegas-López FA, Navarro-Olvera JL, Carrillo-Ruiz JD. Clinical outcomes report in different brachial plexus injury surgeries: a systematic review. Neurosurg Rev [Internet]. 2021;45(1):411–9. Available from: http://dx.doi.org/10.1007/s10143-021-01574-6
21. Clarke HM, Al-Qattan MM, Curtis CG, Zuker RM. Obstetrical Brachial Plexus Palsy: Results Following Neurolysis of Conducting Neuromas-in-Continuity. Plast & Reconstr Surg [Internet]. 1996;97(Supplement):974–82. Available from: http://dx.doi.org/10.1097/00006534-199604001-00014
22. Ferreira JR, Teixeira GQ, Santos SG, Barbosa MA, Almeida-Porada G, Gonçalves RM. Mesenchymal Stromal Cell Secretome: Influencing Therapeutic Potential by Cellular Pre-conditioning. Front Immunol [Internet]. 2018 Dec 4;9:2837. Available from: https://pubmed.ncbi.nlm.nih.gov/30564236
23. Adyaksa G, Suroto H. Apoptosis of proximal stump postganglionic brachial plexus injury, before and after six months post-trauma. Ann Med Surg [Internet]. 2021 Feb 17;63:102156. Available from: https://pubmed.ncbi.nlm.nih.gov/33664944
24. Suroto H, Asriel A, De Vega B, et al. Early and late apoptosis protein expression (Bcl-2, bax and p53) in traumatic brachial plexus injury. *J Musculoskelet Neuronal Interact* 2021;21:528–532.
25. Hems TEJ. Timing of surgical reconstruction for closed traumatic injury to the supraclavicular brachial plexus. J Hand Surg (European Vol [Internet]. 2014;40(6):568–72. Available from: http://dx.doi.org/10.1177/1753193414540074
26. Favila A, Estrella E. Nerve Transfers for Shoulder Function for Traumatic Brachial Plexus Injuries. J Reconstr Microsurg [Internet]. 2013;30(01):59–64. Available from: http://dx.doi.org/10.1055/s-0033-135473718.