We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,300

Open access books available

172,000

International authors and editors

190M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Introductory Chapter: Brachial Plexus Injuries - Past, Present, and Future

Vicente Vanaclocha and Nieves Saiz-Sapena

Additional information is available at the end of the chapter

<http://dx.doi.org/10.5772/intechopen.81675>

1. Introduction

Although they have a low incidence [1–3], brachial plexus injuries continue to be a cause of serious disability [4]. Their victims are mostly young people in the middle of their lives or newborns, always with worrisome long-term consequences [2–4]. Unfortunately brachial plexus lesions can also be the result of iatrogenic injuries [5]. The quality of life of those affected is devastated, with high personal [4, 6], familial [7], and societal costs [8, 9].

Nowadays, road accidents in young people continue to be the most common cause, particularly when the victim is thrown in the air and lands on the shoulder [2, 5, 10]. This is particularly common in developing Third World countries, where people have to recourse to the motorcycle for their daily transportation [1, 11–14], as a car is an option outside their reach. Other causes are wars [15–17] and assaults [18, 19]. The incidence is higher in males than in females [1, 2, 13, 20], probably related to the highest aggressiveness and violent behavior in the former [21]. In newborns brachial plexus injuries are usually due to problems during vaginal delivery [3, 22], particularly in case of a macrosomic fetus [23, 24], common in diabetic mothers [25]. In the developed countries, the fear of unpleasant medicolegal consequences in case of an obstetric brachial plexus injury has induced a significant increase in the proportion of cesarean section deliveries [26, 27]. The incidence of iatrogenic brachial plexus lesions unfortunately continues to be stable overtime with no signs of reduction [5, 28–30]. These iatrogenic lesions are induced while performing lymph node biopsy [5, 31, 32], vessel catheterization [33, 34], on applying radiotherapy in the treatment of cancer [35, 36] repairing upper limb bone fractures [37, 38], in programmed orthopedic procedures [39, 40], due to inadequate patient positioning [41, 42] or when restraining aggressive patients [43]. Preventing these iatrogenic injuries is particularly important, not only because they might lead to ugly medicolegal consequences [28] but because of our motto “*primum non nocere*”

(first do no harm) [44]. Any measure or technical improvement aiming to decrease the chance of these unwanted iatrogenic injuries will always be most welcomed. Knowledge, awareness, and training of all hospital personnel must be a priority in our daily basis [45].

2. Treatment modalities

The age of the patient, the mechanism of injury (blunt or penetrating), the location (proximal or distal in the upper limb), and the extent of the lesion will influence the type and timing of the treatment algorithm as well as the final result [46, 47]. When all brachial plexus roots are affected, particularly if avulsed, there will be very limited treatment options, and the end results will be a severe upper limb disability with a very limited chance of a useful functional recovery [48–50].

Particularly, it is important to find out if the lesion is pre- or postganglionic as the first one has no chance of spontaneous recovery [51]. Magnetic resonance imaging has proven very useful in this respect [52]. Waiting for spontaneous recovery will entail an inexcusable waste of time that will lead to an unsatisfactory recovery [50, 53]. Thus, once the diagnosis of the nerve root avulsion is confirmed, the repair will have to be done as soon as the patient is able to tolerate the surgical procedure needed to be done [54, 55]. The “urgent” repair, a few days after injury, has been reported by some in cases of confirmed avulsion and in clean nerve sections (i.e., glass) [56].

The treatment strategy is based on the mechanism of injury [54], the findings of the physical and neurological examinations [57], and the results of the complementary diagnostic tests (electrodiagnostic studies [58], magnetic resonance imaging [59], and ultrasonography [60]). This last one is relatively inexpensive and can be made available to places with very limited resources [61]. It can also be used intraoperatively to see the anatomy of the damaged nerves, helping to decide if the lesioned nerve segment has to be removed and the gap grafted or a neurolysis will solve the problem [62]. The evolution of their results overtime is particularly useful to locate the lesion(s), assess its severity, and control the response to the treatments (physiotherapy, observation, surgical repair, electrostimulation, etc.) [63]. Computerized myelo-tomography was used in the past to diagnose the nerve root avulsions, but nowadays it has been replaced by magnetic resonance imaging [59, 64–66].

Spontaneous recovery can be expected in most brachial plexus injuries [67], particularly in the case of obstetric patients [68]. Among them the rate of spontaneous recovery is particularly high (66–92%) [69]. Physical therapy is essential to correct muscle contractures and avoid neglect of the damaged limb while waiting for spontaneous recovery [69]. In the case of inadequate recovery, on-time surgical treatment might be indicated [3, 68].

Progressive improvement of the surgical techniques with direct nerve repair, nerve grafting, and particularly with nerve transfers has greatly improved the results in the brachial plexus injuries [47, 70–72]. Direct repair, when at all possible, is still the first choice, provided that there is no tension in the suture line [73]. Nerve grafts are required to cover the gaps, but the results are often not as good as expected [74, 75]. Meanwhile, the nerve transfers have expanded our treatment capabilities with excellent results [72, 76]. They are particularly

useful in nerve injuries affecting the distal parts of the upper limb, as other techniques like the nerve repair, direct or with nerve grafts, yield poor results [47, 70, 77]. The growing axons coming through the nerve repair take so long to reach the hand intrinsic muscles that when they do it find them atrophied and fibrotic [78–81]. Meanwhile, the nerve transfers provide new axons close to the injured muscles with an early and efficient repair [72, 76]. At times an end-to-side nerve transfer can be added to keep the muscles viable, while the growing axons from the direct primary nerve repair to reach their final destination in the motor end plates [82]. Nerve transfers solve the problem of a long distance between the lesion site and the motor end plates to be reinnervated [6, 49, 72, 76]. They can also be used in case of delayed patient referral [83] or dense scar at the primary injury site [84]. Sensory nerve transfer is another very promising area [85, 86], particularly in tetraplegic patients [87, 88], and can also help to control the neuropathic pain [89].

3. Future treatment possibilities

Currently, there is an intense research on pharmacological agents that accelerate the axonal regeneration, shortening the time needed to achieve the reinnervation [90, 91]. Other areas of research are the use of stem cells and growth factors as well as the search for artificial conduits that could substitute the autologous nerve grafts [90, 92]. The most serious injuries, the nerve root avulsions, are still awaiting an effective solution. Reimplantation has been attempted but the results are dismal [50].

Treatment of a complete brachial plexus avulsion with its resultant flail arm poses still a serious challenge [49]. Even with contralateral C₇ nerve root transfer, only some primitive movements are regained with limited use in the daily life [93]. Some have recommended upper limb amputation in these unfortunate cases [94].

Tetraplegic [88] and stroke [95] patient treatments are an area of expansion, aiming to recover some functions in the upper limbs that can improve their quality of life [88, 96]. The rationale behind is to use nerve transfers to recover specific functions (like finger movement) in areas of irreversible spinal cord or motor strip damage [76, 97].

Some technical refinements have been described attempting to reduce the chance of iatrogenic injury in cases of anesthetic brachial plexus block [98, 99]. The use of ultrasonography can be of invaluable help [100]. Some recommendations on patient positioning have also been forwarded [44]. The long-term commitment of every hospital employee is essential to minimize these unwanted mishaps.

4. The future in your own hospital

A final word should be said on how to start, develop, and consolidate a new peripheral nerve unit. This can be a major endeavor that demands continued devotion and long-term commitment. Once you start in this field, first you have to be known and accepted in your own hospital and then in your community. Time and persistence are needed to get the confidence of the referring doctors

as well as the respect of the public. A stepwise and cautious attitude is recommended. While good results not always are acknowledged by our colleagues, a bad case can ruin our reputation. Meanwhile, to get the needed equipment and personnel is something that needs continuous negotiation with the hospital administrators; fighting for resources is also demanded by many other members of your own hospital. But with long-term persistence and unrestricted commitment, one usually achieves the goals, as proven by the authors of one of our following chapters.

5. Conclusions

Brachial plexus injuries continue to pose serious treatment dilemmas. Although the proximal injuries have a reasonable good prognosis, the distal ones not always get a good functional recovery. There has been a big improvement over the years, but research is needed to further improve the functional results, particularly in pan-brachial plexus avulsions. To start a new peripheral nerve unit is an exciting endeavor that demands enthusiasm, long-term commitment, and daily persistence.

Author details

Vicente Vanaclocha^{1*} and Nieves Saiz-Sapena²

*Address all correspondence to: vvanaclo@hotmail.com

1 Department of Neurosurgery, Hospital General Universitario de Valencia, Valencia, Spain

2 Department of Anaesthesiology and Pain Treatment, Hospital 9 de Octubre de Valencia, Valencia, Spain

References

- [1] Faglioni W, Siqueira MG, Martins RS, Heise CO, Foroni L. The epidemiology of adult traumatic brachial plexus lesions in a large metropolis. *Acta Neurochirurgica*. 2014;**156**(5):1025-1028
- [2] Kaiser R, Waldauf P, Ullas G, Krajcova A. Epidemiology, etiology, and types of severe adult brachial plexus injuries requiring surgical repair: Systematic review and meta-analysis. *Neurosurgical Review*. Jul 17 2018. DOI: 10.1007/s10143-018-1009-2. [Epub ahead of print]
- [3] Wall LB, Mills JK, Leveno K, Jackson G, Wheeler LC, Oishi SN, et al. Incidence and prognosis of neonatal brachial plexus palsy with and without clavicle fractures. *Obstetrics and Gynecology*. 2014;**123**(6):1288-1293
- [4] 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 Neurochirurgica*. 2017;**159**(7):1257-1264

- [5] Dengler NF, Antoniadis G, Grolik B, Wirtz CR, König R, Pedro MT. Mechanisms, treatment, and patient outcome of Iatrogenic injury to the brachial plexus-A retrospective single-center study. *World Neurosurgery*. 2017;**107**:868-876
- [6] 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. *The Journal of Hand Surgery, European Volume*. 2012;**37**(7):642-651
- [7] Oskay D, Oksüz C, Akel S, Firat T, Leblebicioğlu G. Quality of life in mothers of children with obstetrical brachial plexus palsy. *Pediatrics International: Official Journal of the Japan Pediatric Society*. 2012;**54**(1):117-122
- [8] Felici N, Zaami S, Ciancolini G, Marinelli E, Tagliente D, Cannatà C. Cost analysis of brachial plexus injuries: Variability of compensation by insurance companies before and after surgery. *Handchir Mikrochir Plast Chir Organ Deutschsprachigen Arbeitsgemeinschaft Handchir Organ Deutschsprachigen Arbeitsgemeinschaft Mikrochir Peripher Nerven Gefasse Organ V*. 2014;**46**(2):85-89
- [9] Pandey N, Gupta D, Mahapatra A, Harshvardhan R. Bed wise cost analysis of in-patient treatment of brachial plexus injury at a Level I trauma Center in India. *Asian Journal of Neurosurgery*. 2014;**9**(2):89-92
- [10] Soldado F, Ghizoni MF, Bertelli J. Thoracodorsal nerve transfer for triceps reinnervation in partial brachial plexus injuries. *Microsurgery*. 2016;**36**(3):191-197
- [11] Babar SM. Peripheral nerve injuries in a Third World country. *The Central African Journal of Medicine*. 1993;**39**(6):120-125
- [12] Barman A, Chatterjee A, Prakash H, Viswanathan A, Tharion G, Thomas R. Traumatic brachial plexus injury: Electrodiagnostic findings from 111 patients in a tertiary care hospital in India. *Injury*. 2012;**43**(11):1943-1948
- [13] Saadat S, Eslami V, Rahimi-Movaghar V. The incidence of peripheral nerve injury in trauma patients in Iran. *Ulus Travma Ve Acil Cerrahi Derg Turk J Trauma Emerg Surg TJTES*. 2011;**17**(6):539-544
- [14] Suleiman FA, Almaaitah AA, Aqrabawi HE. Upper limb birth trauma in a Jordanian population: A prospective study at King Hussein Medical Centre, Amman, Jordan. *JPMA: Journal of the Pakistan Medical Association*. 2016;**66**(11):1422-1426
- [15] Gousheh J. The treatment of war injuries of the brachial plexus. *Journal of Hand Surgery*. 1995;**20**(3 Pt 2):S68-S76
- [16] Razaq S, Yasmeen R, Butt AW, Akhtar N, Mansoor SN. The pattern of peripheral nerve injuries among Pakistani soldiers in the war against terror. *Journal of the College of Physicians and Surgeons--Pakistan*. 2015;**25**(5):363-366
- [17] Chambers JA, Hiles CL, Keene BP. Brachial plexus injury management in military casualties: Who, what, when, why, and how. *Military Medicine*. 2014;**179**(6):640-644

- [18] Kibadi K, Portaels F, Pichot Y, Kapinga M, Moutet F. Stab wounds of the hand and forearm due to Kuluna in Kinshasa (Democratic Republic of Congo): Types of injuries and treatment. *Revue Médicale de Bruxelles*. 2015;**36**(6):468-474
- [19] Bowles AO, Graves DE, Chiou-Tan FY. Distribution and extent of involvement in brachial plexopathies caused by gunshot wounds, motor vehicle crashes, and other etiologies: A 10-year electromyography study. *Archives of Physical Medicine and Rehabilitation*. 2004;**85**(10):1708-1710
- [20] Valent F, Eleopra R, Manganotti P, Passadore P. A population-based study of injuries to the brachial plexus and to the peripheral nerves of the shoulder girdle and upper limb in the Italian region Friuli Venezia Giulia. *Neurosurgical Review*. 2018;**41**(2):519-523
- [21] Stephenson Z, Woodhams J, Cooke C. Sex differences in predictors of violent and non-violent juvenile offending. *Aggressive Behavior*. 2014;**40**(2):165-177
- [22] Grossman JAI, Price A, Chim H. Complications in surgery for brachial plexus birth injury: Avoidance and treatment. *Journal of Hand Surgery*. 2018;**43**(2):164-172
- [23] Ouzounian JG. Risk factors for neonatal brachial plexus palsy. *Seminars in Perinatology*. 2014;**38**(4):219-221
- [24] Okby R, Sheiner E. Risk factors for neonatal brachial plexus paralysis. *Archives of Gynecology and Obstetrics*. 2012;**286**(2):333-336
- [25] Kc K, Shakya S, Zhang H. Gestational diabetes mellitus and macrosomia: A literature review. *Annals of Nutrition & Metabolism*. 2015;**66**(Suppl 2):14-20
- [26] Gonen R, Bader D, Ajami M. Effects of a policy of elective cesarean delivery in cases of suspected fetal macrosomia on the incidence of brachial plexus injury and the rate of cesarean delivery. *American Journal of Obstetrics and Gynecology*. 2000;**183**(5):1296-1300
- [27] Suarez-Easton S, Shalev E, Salim R. Trend in major neonatal and maternal morbidities accompanying the rise in the cesarean delivery rate. *Scientific Reports*. 2015;**5**:12565
- [28] Moore AE, Zhang J, Stringer MD. Iatrogenic nerve injury in a national no-fault compensation scheme: An observational cohort study. *International Journal of Clinical Practice*. 2012;**66**(4):409-416
- [29] Po BT, Hansen HR. Iatrogenic brachial plexus injury: A survey of the literature and of pertinent cases. *Anesthesia and Analgesia*. 1969;**48**(6):915-922
- [30] Huang Y. Iatrogenic injuries of the peripheral nerves: Analysis of 226 cases. *Zhonghua Yi Xue Za Zhi*. 1992;**72**(5):273-276, 318-316
- [31] Davidson T, Malani A, Jones A. Brachial plexus traction injury following axillary node dissection. *Clinical Oncology journal | The Royal College of Radiologists*. 2000;**12**(6):419
- [32] Ferencsik M, Piukovics K, Borbényi Z, Varga G. Peripheral nerve injuries as a rare complication of cervical lymph node excision for diagnostic purposes. *Orvosi Hetilap*. 1990;**131**(27):1465-1467

- [33] Tong Z, Gu Y, Guo L, Guo J, Gao X, Li J, et al. An analysis of complications of brachial and axillary artery punctures. *The American Surgeon*. 2016;**82**(12):1250-1256
- [34] Mulligan B, Espinosa GA, Mafee M. Prevention of brachial plexus injury during transaxillary artery catheterization. *Military Medicine*. 1983;**148**(6):518-520
- [35] Gu B, Yang Z, Huang S, Xiao S, Zhang B, Yang L, et al. Radiation-induced brachial plexus injury after radiotherapy for nasopharyngeal carcinoma. *Japanese Journal of Clinical Oncology*. 2014;**44**(8):736-742
- [36] Chen AM, Wang P-C, Daly ME, Cui J, Hall WH, Vijayakumar S, et al. Dose--volume modeling of brachial plexus-associated neuropathy after radiation therapy for head-and-neck cancer: Findings from a prospective screening protocol. *International Journal of Radiation Oncology, Biology, Physics*. 2014;**88**(4):771-777
- [37] Khademolhosseini M, Abd Rashid AH, Ibrahim S. Nerve injuries in supracondylar fractures of the humerus in children: Is nerve exploration indicated? *Journal of Pediatric Orthopaedics Part B*. 2013;**22**(2):123-126
- [38] Joiner ERA, Skaggs DL, Arkader A, Andras LM, Lightdale-Miric NR, Pace JL, et al. Iatrogenic nerve injuries in the treatment of supracondylar humerus fractures: Are we really just missing nerve injuries on preoperative examination? *Journal of Pediatric Orthopaedics*. 2014;**34**(4):388-392
- [39] Scully WF, Wilson DJ, Parada SA, Arrington ED. Iatrogenic nerve injuries in shoulder surgery. *The Journal of the American Academy of Orthopaedic Surgeons*. 2013;**21**(12):717-726
- [40] Carofino BC, Brogan DM, Kircher MF, Elhassan BT, Spinner RJ, Bishop AT, et al. Iatrogenic nerve injuries during shoulder surgery. *The Journal of Bone and Joint Surgery. American Volume*. 2013;**95**(18):1667-1674
- [41] Shimizu S, Sato K, Mabuchi I, Utsuki S, Oka H, Kan S, et al. Brachial plexopathy due to massive swelling of the neck associated with craniotomy in the park bench position. *Surgical Neurology*. 2009;**71**(4):504-508-509
- [42] Desai KR, Nemcek AA. Iatrogenic brachial plexopathy due to improper positioning during radiofrequency ablation. *Seminars in Interventional Radiology*. 2011;**28**(2):167-170
- [43] Guedes-Corrêa JF, Pereira MR da C, Torráo-Junior FJL, Martins JV, Barbosa DAN. A neglected cause of iatrogenic brachial plexus injuries in psychiatric patients. *Neurosurgery*. Mar 1, 2018;**82**(3):307-311. DOI: 10.1093/neuros/nyx162
- [44] Duffy BJ, Tubog TD. The prevention and recognition of ulnar nerve and brachial plexus injuries. *Journal of Perianesthesia Nursing: Official Journal of the American Society of PeriAnesthesia Nurses*. 2017;**32**(6):636-649
- [45] Blonna D, Wolf JM, Fitzsimmons JS, O'Driscoll SW. Prevention of nerve injury during arthroscopic capsulectomy of the elbow utilizing a safety-driven strategy. *The Journal of Bone and Joint Surgery. American Volume*. 2013;**95**(15):1373-1381

- [46] Mohammad-Reda A. Early post-operative results after repair of traumatic brachial plexus palsy. *Turkish Neurosurgery*. 2013;**23**(1):1-9
- [47] Ali ZS, Heuer GG, Faught RWF, Kaneriya SH, Sheikh UA, Syed IS, et al. Upper brachial plexus injury in adults: Comparative effectiveness of different repair techniques. *Journal of Neurosurgery*. 2015;**122**(1):195-201
- [48] Abou-Al-Shaar H, Karsy M, Ravindra V, Joyce E, Mahan MA. Acute repair of traumatic pan-brachial plexus injury: Technical considerations and approaches. *Neurosurgical Focus*. 2018;**44**(Video Suppl 1):V4
- [49] Liu Y, Lao J, Gao K, Gu Y, Zhao X. Functional outcome of nerve transfers for traumatic global brachial plexus avulsion. *Injury*. 2013;**44**(5):655-660
- [50] Kachramanoglou C, Carlstedt T, Koltzenburg M, Choi D. Long-term outcome of brachial plexus reimplantation after complete brachial plexus avulsion injury. *World Neurosurgery*. 2017;**103**:28-36
- [51] Limthongthang R, Bachoura A, Songcharoen P, Osterman AL. Adult brachial plexus injury: Evaluation and management. *The Orthopedic Clinics of North America*. 2013;**44**(4):591-603
- [52] Karalija A, Novikova LN, Orädd G, Wiberg M, Novikov LN. Differentiation of pre- and postganglionic nerve injury using MRI of the spinal cord. *PLoS One*. 2016;**11**(12):e0168807
- [53] Bertelli JA, Ghizoni MF. Reconstruction of C5 and C6 brachial plexus avulsion injury by multiple nerve transfers: Spinal accessory to suprascapular, ulnar fascicles to biceps branch, and triceps long or lateral head branch to axillary nerve. *Journal of Hand Surgery*. 2004;**29**(1):131-139
- [54] Sinha S, Khani M, Mansoori N, Midha R. Adult brachial plexus injuries: Surgical strategies and approaches. *Neurology India*. 2016;**64**(2):289-296
- [55] Gao K-M, Hu J-J, Lao J, Zhao X. Evaluation of nerve transfer options for treating total brachial plexus avulsion injury: A retrospective study of 73 participants. *Neural Regeneration Research*. 2018;**13**(3):470-476
- [56] Pondaag W, van Driest FY, Groen JL, Malessy MJA. Early nerve repair in traumatic brachial plexus injuries in adults: Treatment algorithm and first experiences. *Journal of Neurosurgery*. 2018:1-7
- [57] Thatte MR, Babhulkar S, Hiremath A. Brachial plexus injury in adults: Diagnosis and surgical treatment strategies. *Annals of Indian Academy of Neurology*. 2013;**16**(1):26-33
- [58] Wiertel-Krawczuk A, Huber J. Standard neurophysiological studies and motor evoked potentials in evaluation of traumatic brachial plexus injuries—A brief review of the literature. *Neurologia i Neurochirurgia Polska*. Sep–Oct 2018;**52**(5):549-554. DOI: 10.1016/j.pjnns.2018.05.004
- [59] Veronesi BA, Rodrigues MB, Sambuy MTCD, Macedo RS, Cho ÁB, Rezende MRD. Use of magnetic resonance imaging to diagnose brachial plexus injuries. *Acta Ortopédica Brasileira*. 2018;**26**(2):131-134

- [60] Zhu Y-S, Mu N-N, Zheng M-J, Zhang Y-C, Feng H, Cong R, et al. High-resolution ultrasonography for the diagnosis of brachial plexus root lesions. *Ultrasound in Medicine & Biology*. 2014;**40**(7):1420-1426
- [61] Chin B, Ramji M, Farrokhyar F, Bain JR. Efficient imaging: Examining the value of ultrasound in the diagnosis of traumatic adult brachial plexus injuries. A systematic review. *Neurosurgery*. Sep 1 2018;**83**(3):323-332. DOI: 10.1093/neuros/nyx483
- [62] Burks SS, Cajigas I, Jose J, Levi AD. Intraoperative imaging in traumatic peripheral nerve lesions: Correlating histologic cross-sections with high-resolution ultrasound. *Operative Neurosurgery (Hagerstown, Md.)*. 2017;**13**(2):196-203
- [63] Marquez Neto OR, Leite MS, Freitas T, Mendelovitz P, Villela EA, Kessler IM. The role of magnetic resonance imaging in the evaluation of peripheral nerves following traumatic lesion: Where do we stand? *Acta Neurochirurgica*. 2017;**159**(2):281-290
- [64] Fuzari HKB, Dornelas de Andrade A, Vilar CF, Sayão LB, Diniz PRB, Souza FH, et al. Diagnostic accuracy of magnetic resonance imaging in post-traumatic brachial plexus injuries: A systematic review. *Clinical Neurology and Neurosurgery*. 2017;**164**:5-10
- [65] Martín Noguerol T, Barousse R, Socolovsky M, Luna A. Quantitative magnetic resonance (MR) neurography for evaluation of peripheral nerves and plexus injuries. *Quantitative Imaging in Medicine and Surgery*. 2017;**7**(4):398-421
- [66] Wade RG, Itte V, Rankine JJ, Ridgway JP, Bourke G. The diagnostic accuracy of 1.5T magnetic resonance imaging for detecting root avulsions in traumatic adult brachial plexus injuries. *The Journal of Hand Surgery, European Volume*. Mar 2018;**43**(3):250-258. DOI: 10.1177/1753193417729587
- [67] Lim SH, Lee JS, Kim YH, Kim TW, Kwon KM. Spontaneous recovery of non-operated traumatic brachial plexus injury. *European Journal of Trauma and Emergency Surgery: Official Publication of the European Society for Trauma and Emergency Surgery*. 2018;**44**(3):443-449
- [68] Abid A. Brachial plexus birth palsy: Management during the first year of life. *Orthopaedics & Traumatology: Surgery & Research*. 2016;**102**(1 Suppl):S125-S132
- [69] Raducha JE, Cohen B, Blood T, Katarincic J. A Review of Brachial Plexus Birth Palsy: Injury and Rehabilitation. *Rhode Island Medical Journal* (2013). 2017;**100**(11):17-21
- [70] Hu C-H, Chang TN-J, Lu JC-Y, Laurence VG, Chuang DC-C. Comparison of Surgical strategies between proximal nerve graft and/or nerve transfer and distal nerve transfer based on functional restoration of elbow flexion: A retrospective review of 147 patients. *Plastic and Reconstructive Surgery*. 2018;**141**(1):68e-79e
- [71] Wali AR, Santiago-Dieppa DR, Brown JM, Mandeville R. Nerve transfer versus muscle transfer to restore elbow flexion after pan-brachial plexus injury: A cost-effectiveness analysis. *Neurosurgical Focus*. 2017;**43**(1):E4
- [72] Ray WZ, Chang J, Hawasli A, Wilson TJ, Yang L. Motor nerve transfers: A comprehensive review. *Neurosurgery*. 2016;**78**(1):1-26

- [73] Bahm J, Gkotsi A, Bouslama S, El-Kazzi W, Schuind F. Direct nerve sutures in (extended) upper obstetric brachial plexus repair. *Journal of Brachial Plexus and Peripheral Nerve Injury*. 2017;**12**(1):e17-e20
- [74] Haninec P, Sámal F, Tomás R, Houstava L, Dubovský P. Direct repair (nerve grafting), neurotization, and end-to-side neurorrhaphy in the treatment of brachial plexus injury. *Journal of Neurosurgery*. 2007;**106**(3):391-399
- [75] O'Grady KM, Power HA, Olson JL, Morhart MJ, Harrop AR, Watt MJ, et al. Comparing the efficacy of triple nerve transfers with nerve graft reconstruction in upper trunk obstetric brachial plexus injury. *Plastic and Reconstructive Surgery*. 2017;**140**(4):747-756
- [76] Forli A, Bouyer M, Aribert M, Curvale C, Delord M, Corcella D, et al. Upper limb nerve transfers: A review. *Hand Surgery & Rehabilitation*. 2017;**36**(3):151-172
- [77] Plate JF, Ely LK, Pulley BR, Smith BP, Li Z. Combined proximal nerve graft and distal nerve transfer for a posterior cord brachial plexus injury. *Journal of Neurosurgery*. 2013;**118**(1):155-159
- [78] Wang ML, Rivlin M, Graham JG, Beredjiklian PK. Peripheral nerve injury, scarring, and recovery. *Connective Tissue Research*. Sep 6 2018:1-7. DOI: 10.1080/03008207.2018.1489381
- [79] Kobayashi J, Mackinnon SE, Watanabe O, Ball DJ, Gu XM, Hunter DA, et al. The effect of duration of muscle denervation on functional recovery in the rat model. *Muscle & Nerve*. 1997;**20**(7):858-866
- [80] Aydin MA, Mackinnon SE, Gu XM, Kobayashi J, Kuzon WM. Force deficits in skeletal muscle after delayed reinnervation. *Plastic and Reconstructive Surgery*. 2004;**113**(6):1712-1718
- [81] Bertelli JA, Ghizoni MF. Nerve root grafting and distal nerve transfers for C5-C6 brachial plexus injuries. *Journal of Hand Surgery*. 2010;**35**(5):769-775
- [82] Liao W-C, Chen J-R, Wang Y-J, Tseng G-F. The efficacy of end-to-end and end-to-side nerve repair (neurorrhaphy) in the rat brachial plexus. *Journal of Anatomy*. 2009;**215**(5):506-521
- [83] Dy CJ, Baty J, Saeed MJ, Olsen MA, Osei DA. A population-based analysis of time to surgery and travel distances for brachial plexus surgery. *Journal of Hand Surgery*. 2016;**41**(9):903-909.e3
- [84] Bahm J, El Kazzi W, Schuind F. Nerve transfers. *Revue Médicale de Bruxelles*. 2011;**32** (6 Suppl):S54-S57
- [85] Bedeschi P, Celli L, Balli A. Transfer of sensory nerves in hand surgery. *Journal of Hand Surgery (Edinburgh, Scotland)*. 1984;**9**(1):46-49
- [86] Bertelli JA. Distal sensory nerve transfers in lower-type injuries of the brachial plexus. *Journal of Hand Surgery*. 2012;**37**(6):1194-1199
- [87] Bertelli JA, Ghizoni MF, Tacca CP. Transfer of the teres minor motor branch for triceps reinnervation in tetraplegia. *Journal of Neurosurgery*. 2011;**114**(5):1457-1460

- [88] Brown JM. Nerve transfers in tetraplegia I: Background and technique. *Surgical Neurology International*. 2011;**2**:121
- [89] Emamhadi M, Andalib S. Nerve transfer to relieve pain in upper brachial plexus injuries: Does it work? *Clinical Neurology and Neurosurgery*. 2017;**163**:67-70
- [90] Panagopoulos GN, Megaloikonomos PD, Mavrogenis AF. The present and future for peripheral nerve regeneration. *Orthopedics*. 2017;**40**(1, 1):e141-e156
- [91] García Medrano B, Barrio Sanz P, Simón Pérez C, León Andrino A, Garrosa García M, Martín Ferrero MA, et al. Regeneration of critical injuries of the peripheral nerve with growth factors. *Revista Española de Cirugía Ortopédica y Traumatología*. 2013;**57**(3):162-169
- [92] Rasulic L. Current concept in adult peripheral nerve and brachial plexus surgery. *Journal of Brachial Plexus and Peripheral Nerve Injury*. 2017;**12**(1):e7-e14
- [93] Zhang C-G, Gu Y-D. Contralateral C7 nerve transfer—Our experiences over past 25 years. *Journal of Brachial Plexus and Peripheral Nerve Injury*. 2011;**6**(1):10
- [94] Siqueira MG, Martins RS, Heise CO, Foroni L. Elective amputation of the upper limb is an option in the treatment of traumatic injuries of the brachial plexus? *Arquivos de Neuro-Psiquiatria*. 2017;**75**(9):667-670
- [95] Zheng M-X, Hua X-Y, Feng J-T, Li T, Lu Y-C, Shen Y-D, et al. Trial of contralateral seventh cervical nerve transfer for spastic arm paralysis. *The New England Journal of Medicine*. 2018;**378**(1):22-34
- [96] Senjaya F, Midha R. Nerve transfer strategies for spinal cord injury. *World Neurosurgery*. 2013;**80**(6):e319-e326
- [97] Bryden AM, Peljovich AE, Hoyen HA, Nemunaitis G, Kilgore KL, Keith MW. Surgical restoration of arm and hand function in people with tetraplegia. *Topics in Spinal Cord Injury Rehabilitation*. 2012;**18**(1):43-49
- [98] Jung MJ, Byun HY, Lee CH, Moon SW, Oh M-K, Shin H. Medial antebrachial cutaneous nerve injury after brachial plexus block: Two case reports. *Annals of Rehabilitation Medicine*. 2013;**37**(6):913-918
- [99] Brull R, Hadzic A, Reina MA, Barrington MJ. Pathophysiology and etiology of nerve injury following peripheral nerve blockade. *Regional Anesthesia and Pain Medicine*. 2015;**40**(5):479-490
- [100] Luftig J, Mantuani D, Herring AA, Nagdev A. Ultrasound-guided retroclavicular approach infraclavicular brachial plexus block for upper extremity emergency procedures. *The American Journal of Emergency Medicine*. 2017;**35**(5):773-777