DERLEME REVIEW

DOI: 10.5336/cardiosci.2021-84385

Brachial Plexus Injury After Cardiac Surgery: Traditional Review

Kalp Cerrahisi Sonrası Brakial Pleksus Yaralanması: Geleneksel Derleme

Mansour JANNATI[a]

[a]Department of Cardiovascular Surgery, Namazee Hospital, Shiraz University of Medical Sciences, Shiraz, IRAN

ABSTRACT Neurologic problems after cardiac surgery are not unusual. Peripheral nerve injury is determined as incomplete or complete or both motor or sensory function loss. The involved nerves are including the brachial plexus, median nerve, ulnar nerve, and radial nerve. One of the prevalent types of peripheral nerve injuries that happen after coronary artery bypass grafting is brachial plexus injury. Brachial plexus injury is an uncommon and under-recognized complication after cardiac surgeries that may lead to a permanent or temporary sensitivity or motor function deficit. Many mechanisms have been recommended for brachial plexus injury after cardiac surgeries comprising sternal retractor placement, internal mammary artery harvesting, hyper-abduction of arm and poor positioning of patients during the operation, and central venous catheter and implantable cardioverter-defibrillator insertion. The diagnosis of brachial plexus injury is challenging due to its complex anatomy. Clinical assessment, magnetic resonance imaging especially high-resolution 3T magnetic resonance neurography, electroneuromyography, and somatosensory evoked potential monitoring are considered as useful methods in the diagnosis of brachial plexus injury. Several strategies are suggested for the prevention and reduction of brachial plexus injury that are including the exact sternal retraction, the prevention from constant and asymmetrical traction, the hands-up position during surgery, and avoiding unsuitable sternal retraction in preparation of internal mammary artery. This review evaluates the occurrence, mechanisms, diagnostic, and preventive measurements of brachial plexus injury after cardiac surgery.

Keywords: Brachial plexus injury; cardiac surgery; neurological injury

ÖZET Kalp cerrahisi sonrası nörolojik problemler olağan dışı değildir. Periferik sinir hasarı, eksik veya tam veya hem motor hem de duyusal fonksiyon kaybı olarak belirlenir. İlgili sinirler; brakial pleksus, medyan sinir, ulnar sinir ve radyal siniri içerir. Koroner arter baypas greftlemesinden sonra meydana gelen yaygın periferik sinir yaralanmalarından biri brakial pleksus yaralanmasıdır. Brakiyal pleksus yaralanması, kalp ameliyatlarından sonra kalıcı veya geçici hassasiyet veya motor fonksiyon eksikliğine yol açabilen nadir görülen ve yeterince tanınmayan bir komplikasyondur. Kalp ameliyatları sonrası brakial pleksus yaralanması için sternal ekartör yerleştirme, iç meme arteri toplama, ameliyat sırasında kolun hiperabdüksiyonu, hastaların kötü konumlandırılması, santral venöz kateter ve implante edilebilir kardiyoverter-defibrilatör yerleştirilmesi gibi birçok mekanizma önerilmiştir. Karmaşık anatomisi nedeniyle brakial pleksus yaralanmasının teşhisi zordur. Klinik değerlendirme, manyetik rezonans görüntüleme, özellikle yüksek çözünürlüklü 3T manyetik rezonans nörografi, elektronöromiyografi ve somatosensöriyel uyarılmış potansiyel monitörizasyonu, brakial pleksus yaralanmasının tanısında faydalı yöntemler olarak kabul edilmektedir. Brakiyal pleksus yaralanmasının önlenmesi ve azaltılması için tam sternal retraksiyon, sabit ve asimetrik traksiyonun önlenmesi, cerrahi sırasında eller yukarı pozisyonu ve internal meme arterinin hazırlanmasında uygun olmayan sternal retraksiyondan kaçınma dâhil olmak üzere çeşitli stratejiler önerilmektedir. Bu derleme, kalp cerrahisi sonrası brakial pleksus hasarının oluşumunu, mekanizmalarını, tanısal ve önleyici ölçümlerini değerlendirmektedir.

Anahtar Kelimeler: Brakial pleksus yaralanması; kalp ameliyatı; nörolojik yaralanma

Neurologic problems after cardiac surgery are not unusual, and the incidence rate of it is about 61%.[1] Primitive reflexes, pout/grasp reflex, ophthalmological abnormalities, and peripheral nervous system disorders are four types of neurologic problems after cardiac surgery.[1] Peripheral nerve injury is determined as incomplete or complete or both motor or sensory function loss. The involved nerves are including the brachial plexus, median nerve, ulnar nerve, and radial nerve.[2] One of the prevalent types of

Correspondence: Mansour JANNATI
Department of Cardiovascular Surgery, Namazee Hospital, Shiraz University of Medical Sciences, Shiraz, IRAN/İRAN
E-mail: Mansour.jannati@mail.com

Peer review under responsibility of Turkiye Klinikleri Cardiovascular Sciences.

Received: 10 May 2021 ***Received in revised form:*** 25 Jul 2021 ***Accepted:*** 12 Aug 2021 ***Available online:*** 18 Aug 2021

peripheral nerve injuries that happen after coronary artery bypass grafting (CABG) is brachial plexus injury (BPI).[3] The brachial plexus is consisting of a group of nerves that comprises of upper root (C5-C6), middle root (C7), and lower root (C8-T1).[4] The rate of BPI occurrence after cardiac surgery varies from 0.5% to 38%, which may be as a result of various causes of it.[5]

BPI is presented in two different types. The first type is considered by a prevalence sensory complaint in the plexus lower roots which includes symptoms such as pain, paresthesia, and numbness, and the second type by a significant motor deficit in the plexus upper and middle roots. The first-mentioned type is more prevalent than the second type and has an outstanding prognosis for recovery.[6] BPI after cardiac surgery commonly leads to sensory deficits, whereas lesions after non-cardiac surgeries mostly cause motor deficits.[7]

The anatomical structures of the brachial plexus make it vulnerable to neuropathy. The brachial plexus has a superficial position that makes it prone to direct injury. The brachial plexus nerve roots are fixed proximally at their origin site and distally where they are connected to the investing fascia, muscles, and other tissues. Therefore, force applied between these sites rises the probability of making a stretch neuropathy. Moreover, there is limited space between the first rib and the clavicle. Therefore, displacement or fracture of the first rib may harm the brachial plexus.[8]

BPI may lead to considerable perioperative morbidity, but 2 to 3 months after the surgery most of the injuries are heal and generally resolved in one year and there is no need for any surgery.[9] In a study, it was shown that the types of injuries vary from mild to severe, and mostly happen in the lower trunk of the brachial plexus.[10] The use of retractor and placement, positioning, cardiopulmonary bypass, and length of surgery may affect the occurrence of BPI.[5]

Having sufficient information about the rate of BPIs after cardiac surgery with knowledge of the pathogenesis and related risk factors can contribute to reducing these complications. Therefore, this review will focus on the mechanisms, diagnostic, and preventive measurements of BPI after cardiac surgery.

METHOD

In this review study, all articles related to BPI after cardiac surgery were evaluated from the year 1970 to 2021. Articles were searched through databases such as PubMed, Web of Science, Scopus, ScienceDirect, Google Scholar, and Cochrane Library using the keywords “brachial plexus injury”, “BPI”, “Cardiac Surgery”, “Coronary Artery Bypass Graft Surgery” and “Median Sternotomy”. A total of 102 articles were extracted in the initial search. After reviewing the abstract of these articles, finally, 40 articles that met the necessary criteria of the present review were selected and evaluated completely.

EPIDEMIOLOGY OF BRACHIAL PLEXUS INJURY

According to the result of the evaluation of studies in this review, it was found that the incidence rate of BPI after cardiac surgery varies from 0.5% to 10.6%. The rate of BPI 5% in patients who underwent open-heart surgery and 85% of the lesion were related to the lower trunk, Hanson et al. reported.[11] In Vahl et al.’s study, the incidence rate of BPI has defined from 1%-10.6% after cardiac surgery and the complication rate was higher in patients with the preparation of the internal mammary artery (IMA).[10] Unlu et al. showed that the rate of BPI was 0.5% in patients who underwent CABG with median sternotomy.[5] In a review article by Chong et al., the incidence rate of the BPI was reported to be between 5.5% to 10% after coronary artery bypass graft surgery.[12]

MECHANISMS OF BRACHIAL PLEXUS INJURY

A number of mechanisms have been suggested as the reason for BPI during cardiac surgery. The factors related to BPI are including concomitant disease, concomitant anatomical predisposition, positioning, surgical, and physiological factors.[6]

Through general anesthesia, particularly after muscle relaxants use, which decrease defensive muscle tone, the patient is at risk for BPI. Peripheral nerve injuries can happen in, compression, stretching, and laceration. During harvesting of the IMA, asymmetrical traction of the sternal halves looks to be related to a higher risk of BPI. It has been shown

that median sternotomy can lead to first rib fractures and the fractured ribs result in BPI.[13]

Many CABG patients have comorbidities that may increase the risk of BPI, such as coagulopathy, diabetes, hypothermia, and peripheral vascular disease.[6] It was shown that older age and longer operation time are associated with the incidence of BPI.[14]

Sternal Retractors

Sternal retractors are located in an intercostal space and cause superior rotation of the first rib and push the clavicles into the retroclavicular space, and both of these directions compress the brachial plexus. Extreme force on the upper ribs with a rate of 4-16% may lead to fractures that may compress the brachial plexus directly. The place of retractor placement may lead to plexus injury, with extra retractors caudal placement, the stress on the first rib decreases, and consequently, the fractures of the upper limb may occur.[9] Wider opening of the sternal retractors which is required to provide a larger surgical field to evaluate special intrathoracic structures, might overstretched plexus and lead to its fibers rupture.[15] Vander Salm et al. performed a cadaver study and showed that while the retractor was placed at the second intercostal space, but not the 4th intercostal space, several fractures were seen. Cephalad retractor placement raised the occurrence of rib fractures that may damage the brachial plexus.[16]

Internal Mammary Artery Harvest

It is suggested that IMA harvest techniques may increase the risk of BPI as a result of the pressure and angle of retraction that used to expose the artery might result in stretching injuries to the brachial plexus.[17] In a study on patients undergoing CABG, it was demonstrated that the rate of BPI is 11% in patients who received IMA grafts in comparison to 1% in patients without IMA harvest.[15] During the harvesting of the IMA, asymmetrical traction of the sternal halves seems to be related to a higher BPI risk.[18] In a study by Unlu et al., in all BPI cases, the common feature was harvesting of the left IMA.[5]

Hyperabduction of Arm

Jackson et al. showed that arm abduction of ≥90°, external rotation, and posterior shoulder dislocation can stretch the brachial plexus. They showed that the plexus was relaxed while the shoulder girdle was raised and when the arms are in the hands-up position, in that way preventing injury of the plexus.[19] In a case report by Lee et al., they recommended that the occurrence of BPI was as a result of stretch or compression while the arm was hyper-abducted (both arms abducted at 100°) during the surgery.[20] Vander Salm et al. evaluated 180 patients in terms of their arm position during cardiac surgery and the incidence of BPI. The incidence of neurological deficits was higher while the arms by the side than when the arms were abducted to 90°, however, it was not significant.[16]

Poor Positioning

The brachial plexus is vulnerable to damage in anesthesia and surgical procedures due to poor positioning. The proximity of it to easily moving bony parts like the first rib, coracoid, clavicle, and humeral head makes it susceptible to the compression that is associated with poor positioning of the patient during operation.[6,20] In a study by Ying et al., the rate of position-associated upper extremity somatosensory evoked potentials (SSEP) monitoring was 2.89%. They recommended that while positioning the patient with a lateral position, attention should be paid to the dependent arm extremities and the upper shoulders to avoid BPI. They also showed that low body mass index and diabetes mellitus were related to higher BPI after microvascular decompression. All the alterations happened during 10 minutes following the patients were positioned.[21]

Vessel Cannulation

Central venous catheter placement is usually essential in cardiac patients for intraoperative hemodynamic monitoring. Frequent punctures of the jugular vein can result in a hematoma that may put the plexus under pressure.[22] Trentman et al. showed that BPI can happen by the placement of subclavian central catheters, but an appropriate method can diminish this problem.[23] In another study by Wang et al. central venous catheterization resulted in contralateral BPI, which might be due to a tight suture that fixed the jugular catheter.[24]

Implantable Cardioverter Defibrillator

Jumper et al. reported a case of BPI after an implantable cardioverter defibrillator (ICD). BPI subsequent to ICD insertion might be associated with vein puncture site for lead access or generator placement or both of them.[25] Xu et al.'s study showed two cases who experience BPI after ICD implantation, the first one was due to continuous injuries to the subclavian artery and vein, and the second patient had a left cephalic vein nicked during cut down and developed a hematoma that induced BPI.[26]

Central Venous Catheter Insertion

The internal jugular vein has a close association with the brachial plexus. The cannulation of the internal jugular vein can result in direct needle injury to the brachial plexus. Hanson et al. in a study on 5,531 patients who underwent cardiac surgery revealed that, in most of the patients, the side of the BPI was related to the side of internal jugular vein cannulation.[11] Mol et al. in a case report showed a case of brachial plexus palsy as a result of internal jugular vein catheterization in a patient which leads to compression by right subclavian artery pseudoaneurysm.[27] Walden in a study demonstrated the subclavian aneurysm as a result of removal of a central venous catheter lead to BPI.[28]

Median Sternotomy

In Unlu et al.'s study, 3 out of 575 patients who underwent CABG's with median sternotomy were detected to have BPI.[5] Kim et al. also revealed two cases who developed a BPI after median sternotomy that one of them was a lower trunk lesion and the other was medial cord lesion.[29] Stangl et al. also showed that 6.5% of cases after median sternotomy diagnosed with BPI, which they believed that level of sternal spread as well as the retractor's placement height independence of the rigidity of the rib cage is responsible for it.[30] Reddy et al. in a prospective study also reported that 7 out of 459 (1.53%) cases, who underwent open-heart surgery with median sternotomy, showed BPI and it was associated with the retraction of the sternum during surgery.[31]

DIAGNOSIS OF BRACHIAL PLEXUS INJURY

The assessment of the BPI is a diagnostic challenge for the physicians. The complex anatomy of the brachial plexus, the distribution of it, and the technical factors make the diagnosis of BPI challenging.[32] Clinical assessment, comprising of history and physical evaluation, may determine the location of the lesion in 30-50% of cases.[33]

Examination of the brachial plexus comprises a comprehensive history of the pain of the upper extremity, evaluation of sensation to pinprick, paraesthesia, and check of muscle groups motor function innervated through the brachial plexus. The motor examination contains elevation of the scapula, abduction, adduction, the arms medial and lateral rotation, the forearms supination and flexion, ulnar hand flexion, the opposition and flexion thumb, the forearm and phalanges extension, and the hand radial extension and the thumb extension.[34]

Magnetic resonance imaging (MRI) has the ability to demonstrate the location and the degree of the BPI and it may be capable to define the affecting factors. It also can provide information for other diagnoses.[35] Rafael Tronco Alves et al. also showed the effective role of MRI in the diagnosis of BPI in post□sternotomy injuries.[36] Torres et al. suggested that a modified MRI technique facilitated the evaluation and diagnosis of BPI.[32] According to Vargas et al.'s study, MRI is the best method to reveal nerve root avulsion.[37] Chhabra et al. reported that high-resolution 3T MR neurography with three-dimensional imaging was able to describe the situation of nerve roots and to determine the site and amount of damage in the distal part of plexus.[38]

Electroneuromyography (EMG) makes possible the visualization of distal lesions of the brachial plexus. It also demonstrates the differentiation between edema and demyelination of trunk and cord lesions.[37] Chanlalit et al. showed that a combination of EMG and clinical findings associated well with the diagnosis of BPI.[39]

It is reported that the use of SSEP monitoring of the nerves may be useful in the prediction of peripheral nerve injury in cardiac surgery.[40]

PREVENTION OF BRACHIAL PLEXUS INJURY

The risk of BPI will be reduced through proper positioning, avoiding prolonged and extreme traction on the rib cage, and thoracoscopic harvesting of LIMA.[41] Lin et al., suggested that BPI could be diminished by a lower position and the smallest probable opening for the sternal retractor, precise median sternotomy, and the prevention from constant and asymmetrical traction on the sternal halves.[18] According to Unlu et al.'s study to reduce the risk of BPI the exact sternal retraction and the use of the hands-up position are important. Also, it should be avoided from unsuitable sternal retraction in preparation of IMA.[5] It is also recommended that the use of retractors designed for asymmetric traction should be done with great caution. Also, caudal localization of the retractor is recommended.[6] It is suggested that postoperative neurologic evaluation should be done in all patients to let initial detection and treatment of nerve lesions.[42] Jellish et al. showed that hands-up positioning during asymmetric sternal retraction for IMA harvest might decrease the incidence of BPI.[43]

MANAGEMENT AND TREATMENT OF BRACHIAL PLEXUS INJURY AFTER SURGERY

To manage the postoperative BPI following treatments are recommended. Retarding muscle atrophy and facilitating the reeducation of the impaired muscles may be done by physical therapy with galvanic muscle stimulation. Stretching training and passive ROM are significant to prevent contracture. Moreover, isotonic and isometric strengthening training, with the progressive rise of intensity and numbers, are effective to improve power and endurance.[20] According to Hudson et al., the management of the BPI should be mainly conservative, with splintage and treatment to avoid inherent hand contractures and to afford support for the hand until the recovery happens. Surgical intervention may be used if no retrieval has happened in 3-5 months when there is a persistent loss of function or in the presence of progressive pain in the neck.[44]

In surgical treatment information about patterns of injury, surgery timing, prioritization in function restoration, and management of expectations of patients should be considered. The surgical management options are including nerve grafting, neurolysis, and nerve transfers and should be accomplished within 6 months of injury. The free functioning muscle transfers can develop function in the acute as well as late setting. Modern patient-specific treatment leads to consistent restoration of flexion of elbow as well as stability of shoulder with the potential of the hand prehension.[45]

CONCLUSION

Nerve injuries, including BPI, after cardiac surgery, are well-recognized complications. BPI may be a source of postoperative morbidity in some patients. Several mechanisms have been suggested for BPI after cardiac surgeries including sternal retractors placement, IMA harvesting, hyper-abduction of arm and poor positioning of patients during surgery, vessel cannulation, and central venous catheter and ICD insertion. Focused preventive strategies including the exact sternal retraction, the prevention from constant and asymmetrical traction, the hands-up position, and avoiding unsuitable sternal retraction in preparation of IMA might decrease both the frequency and severity of BPI.

Source of Finance

During this study, no financial or spiritual support was received neither from any pharmaceutical company that has a direct connection with the research subject, nor from a company that provides or produces medical instruments and materials which may negatively affect the evaluation process of this study.

Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

This study is entirely author's own work and no other author contribution.

REFERENCES

1. Shaw PJ, Bates D, Cartlidge NE, Heaviside D, Julian DG, Shaw DA. Early neurological complications of coronary artery bypass surgery. Br Med J (Clin Res Ed). 1985;291(6506): 1384-7. [Crossref] [PubMed] [PMC]
2. Kroll DA, Caplan RA, Posner K, Ward RJ, Cheney FW. Nerve injury associated with anesthesia. Anesthesiology. 1990;73(2):202-7. [Crossref] [PubMed]
3. Hallikainen H, Partanen J, Mervaala E. The importance of neurophysiological evaluation of plexus brachialis injury caused by open heart surgery. Electromyogr Clin Neurophysiol. 1993;33(2):67-71. [PubMed]
4. Neal JM, Gerancher JC, Hebl JR, Ilfeld BM, McCartney CJ, Franco CD, et al. Upper extremity regional anesthesia: essentials of our current understanding, 2008. Reg Anesth Pain Med. 2009;34(2):134-70. [Crossref] [PubMed] [PMC]
5. Unlu Y, Velioglu Y, Kocak H, Becit N, Ceviz M. Brachial plexus injury following median sternotomy. Interact Cardiovasc Thorac Surg. 2007;6(2):235-7. [Crossref] [PubMed]
6. Ben-David B, Stahl S. Prognosis of intraoperative brachial plexus injury: a review of 22 cases. Br J Anaesth. 1997;79(4):440-5. [Crossref] [PubMed]
7. Uribe JS, Kolla J, Omar H, Dakwar E, Abel N, Mangar D, et al. Brachial plexus injury following spinal surgery. J Neurosurg Spine. 2010;13(4):552-8. [Crossref] [PubMed]
8. Kirsh MM, Magee KR, Gago O, Kahn DR, Sloan H. Brachial plexus injury following median sternotomy incision. Ann Thorac Surg. 1971;11(4):315-9. [Crossref] [PubMed]
9. Seyfer AE, Grammer NY, Bogumill GP, Provost JM, Chandry U. Upper extremity neuropathies after cardiac surgery. J Hand Surg Am. 1985;10(1):16-9. [Crossref] [PubMed]
10. Vahl CF, Carl I, Muller-Vahl H, Struck E. Brachial plexus injury after cardiac surgery. The role of internal mammary artery preparation: a prospective study on 1000 consecutive patients. J Thorac Cardiovasc Surg. 1991;102(5):724-9. [Crossref] [PubMed]
11. Hanson MR, Breuer AC, Furlan AJ, Lederman RJ, Wilbourn AJ, Cosgrove DM, et al. Mechanism and frequency of brachial plexus injury in open-heart surgery: a prospective analysis. Ann Thorac Surg. 1983;36(6):675-9. [Crossref] [PubMed]
12. Chong AY, Clarke CE, Dimitri WR, Lip GY. Brachial plexus injury as an unusual complication of coronary artery bypass graft surgery. Postgrad Med J. 2003;79(928):84-6. [Crossref] [PubMed] [PMC]
13. Ilgen Uslu F, Simsek Erdem N. Permanent pain and brachial plexus injury after coronary bypass grafting: Case report and reviwing the literature. Agri. 2019;31(1):42-5. [PubMed]
14. Basel H, Aydin U, Hazar A, Dostbil A, Tekin Ö, Kapan S. Brachial plexus injury due to median sternotomy and lima harvesting. PAKISTAN JOURNAL OF MEDICAL SCIENCES. 2009;25(3):424-7. [PubMed]
15. Grocott HP, Clark JA, Homi HM, Sharma A. "Other" neurologic complications after cardiac surgery. Semin Cardiothorac Vasc Anesth. 2004;8(3):213-26. [Crossref] [PubMed]
16. Vander Salm TJ, Cereda JM, Cutler BS. Brachial plexus injury following median sternotomy. J Thorac Cardiovasc Surg. 1980; 80(3):447-52. [Crossref] [PubMed]
17. Jellish WS, Martucci J, Blakeman B, Hudson E. Somatosensory evoked potential monitoring of the brachial plexus to predict nerve injury during internal mammary artery harvest: intraoperative comparisons of the Rultract and Pittman sternal retractors. J Cardiothorac Vasc Anesth. 1994;8(4):398-403. [Crossref] [PubMed]
18. Lin PY, Luo CY, Kan CD, Yang YJ, Jou IM. Brachial plexus injury following coronary artery bypass surgery: a case report. Kaohsiung J Med Sci. 2000;16(12):638-42. [PubMed]
19. Gil HY, Yun MJ, Kim JE, Lee MA, Kim DH. Brachial plexus injury following median sternotomy. Korean J Anesthesiol. 2012;63(3): 286-7. [Crossref] [PubMed] [PMC]
20. Lee PH, Hsieh LF, Hong CZ. Unilateral brachial plexus injury as a complication of thoracoscopic sympathectomy for hyperhidrosis: a case report. Arch Phys Med Rehabil. 2003;84(9):1395-8. [Crossref] [PubMed]
21. Ying T, Wang X, Sun H, Tang Y, Yuan Y, Li S. Clinical Usefulness of Somatosensory Evoked Potentials for Detection of Peripheral Nerve and Brachial Plexus Injury Secondary to Malpositioning in Microvascular Decompression. J Clin Neurophysiol. 2015;32(6):512-5. [Crossref] [PubMed]
22. Rieke H, Benecke R, DeVivie ER, Turner E, Crozier T, Kettler D. Brachial plexus lesions following cardiac surgery with median sternotomy and cannulation of the internal jugular vein. J Cardiothorac Anesth. 1989;3(3):286-9. [Crossref] [PubMed]
23. Trentman TL, Rome JD, Messick JM, Jr. Brachial plexus neuropathy following attempt at subclavian vein catheterization. Case report. Reg Anesth. 1996;21(2):163-5. [PubMed]
24. Wang J, Liu F, Liu S, Wang N. An Uncommon Cause of Contralateral Brachial Plexus Injury Following Jugular Venous Cannulation. Am J Case Rep. 2018;19:289-91. [Crossref] [PubMed] [PMC]
25. Jumper N, Radotra I, Witt P, Campbell NG, Mishra A. Brachial plexus impingement secondary to implantable cardioverter defibrillator: A case report. Arch Plast Surg. 2019:594-8. [Crossref] [PubMed] [PMC]
26. Xu J, Card P, Watts E, Escobar GA, Tobler G, Paydak H. Combined vascular and neurologic injury after cephalic vein cutdown approach for ICD implantation. Case Rep Intern Med. 2017;4(4):75-7. [Crossref]
27. Mol TN, Gupta A, Narain U. Brachial plexus compression due to subclavian artery pseudoaneurysm from internal jugular vein catheterization. Indian J Nephrol. 2017;27(2): 148-50. [Crossref] [PubMed] [PMC]
28. Walden FM. Subclavian aneurysm causing brachial plexus injury after removal of a subclavian catheter. Br J Anaesth. 1997;79(6): 807-9. [Crossref] [PubMed]
29. Kim Y, Kim J, Kim Y, Kwon J. Two Cases of Brachial Plexus Injury Following Median Sternotomy. J Korean EMG Electrodiagn Med. 2008;10(2):152-6. [Crossref]
30. Stangl R, Altendorf-Hofmann A, von der Emde J. Brachial plexus lesions following median sternotomy in cardiac surgery. Thorac Cardiovasc Surg. 1991;39(6):360-4. [Crossref] [PubMed]
31. Reddy KV, Satyanarayana PV, Murthy J, Rao P, Rao CM, Rama RP, et al. Brachial plexus and related lesions after median sternotomy. Neurol India. 1997;45(3):162-5. [PubMed]
32. Torres C, Mailley K, Del Carpio O'Donovan R. MRI of the brachial plexus: modified imaging technique leading to a better characterization of its anatomy and pathology. Neuroradiol J. 2013;26(6):699-719. [Crossref] [PubMed] [PMC]
33. Balakrishnan G, Kadadi BK. Clinical examination versus routine and paraspinal electromyographic studies in predicting the site of lesion in brachial plexus injury. J Hand Surg Am. 2004;29(1):140-3. [Crossref] [PubMed]
34. Brazis P, Masdeu J, Biller J. Localization in clinical neurology 3rd ed. Boston: Little Brown; 1996.
35. Posniak HV, Olson MC, Dudiak CM, Wisniewski R, O'Malley C. MR imaging of the brachial plexus. AJR Am J Roentgenol. 1993;161(2):373-9. [Crossref] [PubMed]
36. Rafael Tronco Alves G, Henz Concatto N, Harrington D, McCann C, Hochhegger B, Irion K. The role of MRI in the diagnosis of post-sternotomy injuries of the brachial plexus. Journal of Cardio-Thoracic Medicine. 2015;3(1):281-3. [Link]
37. Vargas MI, Beaulieu J, Magistris MR, Della Santa D, Delavelle J. [Clinical findings, electroneuromyography and MRI in trauma of the brachial plexus]. J Neuroradiol. 2007; 34(4):236-42. [Crossref] [PubMed]

38. Chhabra A, Thawait GK, Soldatos T, Thakkar RS, Del Grande F, Chalian M, et al. High-resolution 3T MR neurography of the brachial plexus and its branches, with emphasis on 3D imaging. AJNR Am J Neuroradiol. 2013;34(3):486-97. [Crossref] [PubMed] [PMC]

39. Chanlalit C, Vipulakorn K, Jiraruttanapochai K, Mairiang E, Chowcheun P. Value of clinical findings, electrodiagnosis and magnetic resonance imaging in the diagnosis of root lesions in traumatic brachial plexus injuries. J Med Assoc Thai. 2005;88(1):66-70. [PubMed]

40. Hickey C, Gugino LD, Aglio LS, Mark JB, Son SL, Maddi R. Intraoperative somatosensory evoked potential monitoring predicts peripheral nerve injury during cardiac surgery. Anesthesiology. 1993;78(1):29-35. [Crossref] [PubMed]

41. Chandra B, Sharma VK. Bilateral Hand Wasting After Coronary Artery Bypass Graft Surgery. J Invasive Cardiol. 2020;32(3):E74. [PubMed]

42. Bonatti J, Coulson AS, Bakhshay SA, Posch L, Sloan TJ. The subclavian and axillary arteries as inflow vessels for coronary artery bypass grafts--combined experience from three cardiac surgery centers. Heart Surg Forum. 2000;3(4):307-11; discussion 11-2. [PubMed]

43. Jellish WS, Blakeman B, Warf P, Slogoff S. Hands-up positioning during asymmetric sternal retraction for internal mammary artery harvest: a possible method to reduce brachial plexus injury. Anesth Analg. 1997;84(2):260-5. [Crossref] [PubMed]

44. Hudson D, Boome R, Sanpera I. Brachial plexus injury after median sternotomy. The Journal of hand surgery. 1993;18(2):282-4. [Crossref] [PubMed]

45. Noland SS, Bishop AT, Spinner RJ, Shin AY. Adult Traumatic Brachial Plexus Injuries. J Am Acad Orthop Surg. 2019;27(19):705-16. [Crossref] [PubMed]