A Practical Guide to Exploration of The Injured Brachial Plexus

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Abstract

The management of brachial plexus injuries continues to evolve. Surgical treatment in the first several months typically begins with direct exploration of the plexus to confirm the location and type of injury. The literature is replete with historic and emerging techniques for nerve repair and transfer; however, a practical guide to the routine exploration of the plexus is not readily accessible. Anatomic variations and traumatic distortion make knowledge of multiple landmarks and common findings paramount to identify key structures while avoiding iatrogenic injury. This text details a step-by-step guide to anterior exploration of the brachial plexus with technical pearls.

Keywords
- brachial plexus
- brachial plexus injury
- nerve exploration
- nerve injury
- nerve palsy
- nerve transfer
- neurotization
- plexopathy

Introduction

Management of brachial plexus injury is a complex task with a steep learning curve. Acute and subacute primary surgical treatment will involve combinations of neurolysis, neuroma resection, and nerve repair/grafting/transfer. Exploration is necessary to confirm the location and type of injury prior to proceeding with reconstruction. Textbooks detail atraumatic anatomy and surgical approaches; however, scarring and distortion of the neurovascular structures make it compulsory to have knowledge of multiple landmarks for safe exposure. A high number of brachial plexus injuries in the senior authors' referral center has led to observations on consistent findings not previously assimilated into a comprehensive guide. This article describes the technique of brachial plexus exploration with pearls for localizing relevant anatomy within injured tissues.

Anatomy

The brachial plexus consists of the 5th through 8th cervical and first thoracic nerve roots, with occasional addition from the C4 root in a prefixed plexus or the T2 root in a postfixed plexus. These combine to form three trunks within the posterior triangle of the neck, an area the omohyoid muscle further divides into the superior omotrapezial and inferior omoclavicular triangles. Erb's point marks where the suprascapular nerve (SSN) branches laterally off the upper trunk. The three trunks divide into anterior and posterior divisions. Conceptually, these form three cords that are named after their relation to the axillary artery. The medial and lateral cords pass over the artery, while the posterior cord passes behind it, followed by differentiation into the terminal branches.[1]

The upper and middle trunks lie in the larger omotrapezial or occipital triangle, while the more anatomically

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variable lower trunk lies in the smaller omoclavicular triangle. The supraclavicular plexus is located between the anterior and middle scalenes, named after their attachments to the respective tubercles of the vertebral transverse processes. The divisions are naturally retroclavicular, while the cords and terminal branches are infraclavicular, although traction injury may translate the entire plexus distally. Additional anatomy is discussed in the technique description.

Indications/Contraindications

Patients are evaluated for concomitant injuries, which are present in 75% of brachial plexus injuries.[2,3] The mechanism of injury and sensorimotor deficit pattern suggests the level of injury, while the presence or absence of any spontaneous recovery indicates injury severity. Rhomboid, serratus anterior, or diaphragm paresis suggest avulsion or root-level injury, as their innervation is from proximal branches within the plexus (dorsal scapular, long thoracic, and phrenic nerves, respectively). Preserved supra- and infraspinatus function suggests infraclavicular injury, at the cord or terminal branch level, since the suprascapular nerve branches off from the upper trunk and is the only practically examined terminal branch at this level. Electrodiagnostic studies are helpful in detecting nerve recovery prior to clinical reanimation; however, as they cannot predict the degree or timeframe of recovery, the treatment plan is predominantly formulated by the physical examination. The presence of a sensory nerve action potential, however, is confirmatory of a preganglionic lesion, which can guide one to consider early exploration and prepare for nerve transfers. MRI is helpful in predicting the level and extent of injury if performed after the initial edema has resolved, at least one month, although it cannot yet serve as a substitute for intraoperative visualization and nerve stimulation to confirm the injury. Pseudomeningocele on MRI does not always indicate avulsion and, in fact, gives a 20% false positive rate for avulsions.[4]

With the exception of penetrating trauma such as lacerations, nerve exploration should be delayed for at least 6 weeks. Associated vascular injury, comprising 5 to 20% of associated injuries, along with other associated injuries, will have time to heal.[2,3]Wallerian degeneration takes place over the first 4 weeks, so prior to this, intraoperative nerve stimulation of an axonotmetic injury may be falsely positive. Suspicion of neuropraxic injury should be an indication to wait at least 3 months, as one would otherwise not know the recovery potential of a neuroma in continuity. Prior to this, potential motor nerves for transfers may not have sufficient clinical recovery from neuropraxic injury to be recognized as viable donors. Conversely, praxic sensory nerves with recovery potential might be misinterpreted as being available as nerve grafts, and their harvest will leave anesthetic patches that are not as well-tolerated as alternative donor grafts. There is no evidence-based strict upper limit to exploration; however, it is generally well-accepted that after 12 to 18 months, the recovery potential is limited.

Prior to surgery, electrical stimulation is performed to keep muscles receptive for reinnervation, and it is continued postoperatively for 4 weeks after the initial immobilization period.[5]Range of motion exercises and resting splints are employed to prevent joint contractures. Patients are counseled to have appropriate expectations and an understanding of residual deficits despite “recovery.”

Surgical Technique

Setup

The patient is positioned supine with the neck rotated to the opposite side. A soft roll placed under the midline between the scapulae gently extends the neck and opens the suprascapular area. If nerve grafting is anticipated, rolls should also be placed under the hips to internally rotate the legs for sural nerve harvest. The neck, chest, and entire upper extremity are prepped into the sterile field. As a double level injury is possible, one should always be prepared for extensive plexus exploration.[1]The clavicle, acromioclavicular joint, sternocleidomastoid (SCM), and anterior trapezius border are marked onto the skin. A curvilinear incision parallel with Langers lines is marked between the lateral SCM and the anterior trapezius, two fingerbreadths above the superior border of the clavicle. This “necklace” incision heals relatively aesthetically, yet the lax skin here allows sufficient exposure of the entire plexus.

Hemostasis is facilitated by subcutaneous (SC) infiltration of epinephrine with a concentration of 1:100,000, achieved by diluting 1 mL of 1:1000 epinephrine into 100 mL of normal saline. The use of both SC lidocaine as well as anesthetic muscular relaxants are avoided, as they interfere with nerve stimulation intraoperatively. This same solution can be used on sponges to bathe tissues during dissection.

Superficial Exposure

The clavipectoral fascia and platysma are divided deep to the subcutaneous tissue (►**Fig. 1**). Supraclavicular nerves, the sensory branches of the ansa cervicalis, are encountered in the subplatysmal layer and preserved to avoid sensory loss and painful neuroma formation. They function as anatomic markers and, uncommonly, nerve grafts or donors for transfer.

The spinal accessory nerve (SAN) is identified first. This extraplexal nerve is rarely injured in traction type injuries, therefore it is a common donor for nerve transfer. Proximally, identification is possible where the SAN travels through the SCM in a third of patients and posterior to it in the remainder, which is useful if unable to locate the nerve distally with an extended zone of injury.[6]More typically, the SAN is identified distally after it has already innervated the upper trapezius in conjunction with cervical plexus contributions via the ansa cervicalis. Four landmarks are useful for SAN identification distally. The first is the trapezius, where the SAN is 2 to 3 cm deep to the anterior border of the muscle within the fascial tissues. The characteristic course of the nerve as it is descending down away from the surgeon sitting at the head of the patient is distinct from the supraclavicular sensory nerves, which tend to remain superficial as they traverse laterally. The authors have observed that the superior prominence of the acromioclavicular joint is an excellent estimate of the level at which the SAN should be searched for. This landmark is easily identifiable and reliable even in muscular patients, where an anteriorly placed trapezius causes the nerve to lie deeper under the muscle (►Fig. 1). A large sensory nerve will often be seen in the lateral aspect of the incision, superficial to the plane in which the SAN lies deep under the anterior surface of the trapezius. Finally, a large accompanying vein will be present in proximity to the SAN. Bleeding from this friable vessel while searching for the SAN is quite common, and one should resist hasty blind cauterization to avoid iatrogenic injury to the SAN. Confirmation of the nerve is achieved by both electrical stimulation as well as visualization of its oblique posterior orientation superficially before going deep in a vertical direction (►Fig. 2).

A vessel loop is placed around the nerve for later identification, secured with clips instead of weighted instruments that may stretch and injure the nerve. As long as the nerve is divided sufficiently inferiorly, distal to the upper trapezius branches, harvest for nerve transfer will only denervate the lower trapezius. Strength and function of the upper trapezius are maintained, such that the insertion can still be transferred for stabilization and shoulder abduction in the future. Proximal SAN exploration should be minimized to preserve the upper trapezius motor branch. If SSN neurotization is performed, SAN harvest as distal as possible will minimize distance for reinnervation and allow direct coaptation. Division of the fascia and fibers of the anterior trapezius will allow a path for a tension-free nerve transfer.

Dissection proceeds medially, where the lateral aspect of the SCM clavicular head is divided. The omohyoid, located between the superficial and deep cervical fascial layers, divides the posterior triangle of the neck as previously stated. The larger superior triangle contains the SAN and cervical plexus, while the smaller inferior triangle houses the lower trunk and transverse cervical artery (TCA). The omohyoid is detached proximally and reflected laterally (►Fig. 3), serving as a marker for the oblique orientation of the SSN,

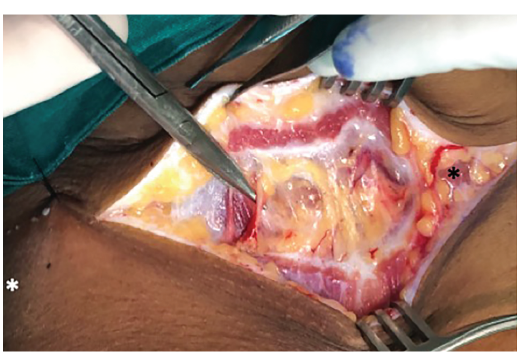

Fig. 1 Superficial dissection of the neck demonstrating the sternocleidomastoid (SCM) medially (black asterisk) and the superficial fascia overlying the trapezius laterally. The instrument tips highlight a sensory nerve that heralds the spinal accessory nerve (SAN) found deeper. This corresponds to the acromioclavicular joint prominence (white asterisk).

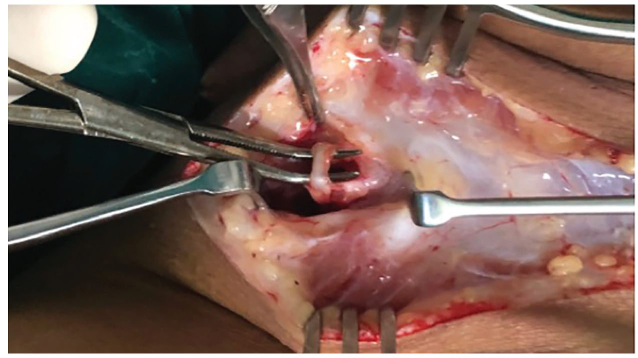

Fig. 2 The spinal accessory nerve (SAN) is lifted from its location 2c m deep to the anterior border of the trapezius.

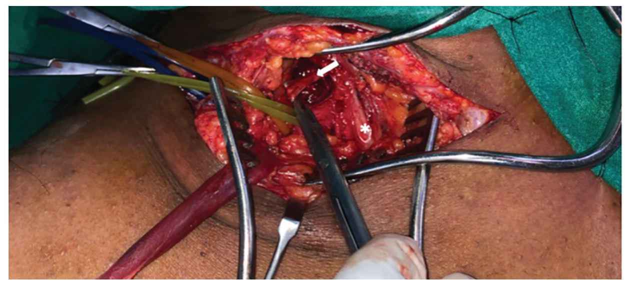

Fig. 3 Retractors have been placed orthogonally. The omohyoid is reflected inferolaterally. The phrenic nerve (asterisk) overlies the anterior scalene, while the long thoracic nerve (arrow) is hooked by the instrument. Note that the vessel loop is tractioned by an instrument for demonstration; however, care is taken to not have constant traction on these structures.

which also traverses the suprascapular notch. The intersection of the external jugular vein with the lateral border of the SCM is a landmark for the C5 nerve root. The internal jugular vein (IJV) is seen longitudinally in the medial aspect of the dissection, where it is part of the carotid sheath with the common carotid artery and vagus nerve. Care should be taken when placing a self-retaining retractor between the inferior and lateral-retracted omohyoid and the jugular vein superomedially.

The interscalene or periplexal fat pad rich in lymphatics will be encountered next and should be released as an inferior and lateral-based flap to be replaced prior to closure. It serves as a protective cover for the plexus after nerve repair and may facilitate nerve healing. Dissection should proceed with special caution on the left side, given the proximity of the thoracic duct.

Deep Exposure

The anterior scalene is oriented longitudinally with the phrenic nerve laying directly on its superficial surface (►Fig. 3), sometimes on the lateral edge. The phrenic nerve can be confirmed by both stimulation, noting diaphragmatic contraction if functioning, as well as its unique orientation "going away," travelling from superolateral to inferomedial, while all other plexus structures "come toward" by travelling laterally. Occasionally, the phrenic nerve is not readily visualized due to thick deep transverse cervical fascia.

The technique of following the C4 root to the nerve is described, however we do not routinely expose C4. The phrenic nerve serves as a guide to the C5 root, which emerges at its intersection with the lateral edge of the anterior scalene. If the C5 contribution to the phrenic nerve is disrupted, however, clinical consequences are unlikely, as it is mainly composed of C4 fibers.

An accessory phrenic nerve will be present in 36 to 62%, most often from the nerve to the subclavius or the ansa cervicalis. It is at risk with proximal dissection or mobilization of the main nerve and should be assumed to provide significant diaphragmatic innervation. We consider the phrenic nerve the medial extent of our exposure, such that more proximal root injury can be effectively considered an avulsion. If the phrenic nerve is adherent to the C5 neuroma, it is not necessary to separate the two. As we rarely utilize the phrenic nerve as a donor, we do not routinely mobilize it off the anterior scalene or divide the muscle, although many texts describe this.

The middle scalene will be directly lateral to the anterior scalene, with plexus roots emerging between the two. The long thoracic nerve (LTN) will be appreciated atop, or occasionally through, the middle scalene. It will travel parallel to the plexus in the supraclavicular region, in proximity to the SSN, approximately 2 cm posterior to clavicle before traveling deep (►**Fig. 3**). Since it branches from the root level, it is important to locate and stimulate the LTN, as its function suggests that the C5 and C6 roots are intact and amenable to neurotization. A C7 contribution to the LTN is present in 40%.[1] Other proximal branches, such as the dorsal scapular nerve from C5, are rarely seen.

The C5 root is the most superficial. If the medial anatomy is distorted, we dissect more lateral and distal, locate the SSN by its oblique orientation, superomedial to inferolateral, parallel and deep to the omohyoid. The SSN is then traced proximally to Erb's point, its origin off the upper trunk. Injury often occurs at this level, due to the differential mobility of the relatively fixed upper trunk, compared with the untethered divisions and SSN. The upper trunk can subsequently be traced more proximally to its roots. The slightly larger C6 root is caudal and dorsal to C5, to which it is typically adherent. The prominent anterior tubercle of the C6 vertebra (Chassaignac's tubercle) can be palpated. The subsequent C7 and C8 roots are the largest and sequentially more caudal and dorsal.

The upper trunk trifurcates into the SSN, posterior, and anterior divisions, from lateral to medial, respectively (►**Fig. 4**). In 40%, there is true trifurcation; however, more typically the SSN branches from the upper trunk an average of 4 mm proximal to the origin of the divisions. A useful way to recall the anatomy here is the phrase, "two converge, 2 diverge, and 2 emerge," referring to two roots forming the upper trunk, followed by divergence of the two divisions, with additional visualization of the SSN and the nerve to the subclavius, the latter occasionally seen as a small medial branch off the upper roots.

The C7 nerve is termed the middle trunk as it continues distally (►**Fig. 5**). The TCA will be appreciated in a horizontal

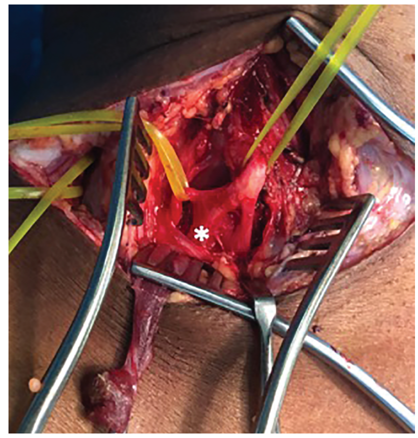

Fig. 4 The upper trunk (upper right vessel loop) trifurcates into the suprascapular nerve (SSN) (left vessel loop), posterior division (asterisk), and anterior division most medially.

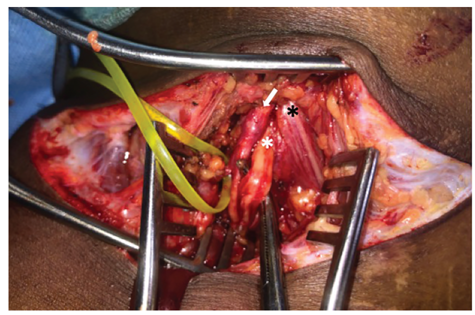

Fig. 5 The C7 root continues as the middle trunk (white asterisk), deep and inferior to the upper trunk (white arrow), where a loop has been placed around the suprascapular nerve (SSN) branch. Both trunks emerge under the anterior scalene with its overlying phrenic nerve (black asterisk).

orientation, parallel to the clavicle, ventral to the C7 nerve root. It can be ligated without appreciable consequence, as can the dorsal scapular and suprascapular vessels in proximity to the divisions behind the clavicle. The T1 root lies deepest and can be visualized with inferior traction on the clavicle. The lower plexus roots surround the first rib and are in close proximity to the pleura. The lower trunk is in proximity to the subclavian vessels, as it lies on the anterior surface of the middle and posterior scalenes.

It is important to recognize that the injury can be at variable, sometimes multiple levels within the plexus. The lower roots are particularly prone to avulsion injury, as they have less stabilizing connective tissue to their vertebral egresses and are oriented more horizontal than the oblique upper roots. Avulsions can displace the roots distal and lateral, however occasionally avulsed roots remain in their vertebral foraminae. In these cases, the nerves will appear to be in good condition without neuroma or swelling. Dense sensorimotor deficit, lack of clinical recovery of lower root muscles, and intraoperative scalene scarring and fibrosis suggest avulsion injury, and appropriate treatment should proceed with nerve transfers rather than misinterpretation as an intact plexus. If electrical stimulation demonstrates activity through a neuroma, and for various reasons it is decided not to resect and graft, we will apply continuous "tetanic" stimulation for several minutes, as this may help recovery and does not seem to have a negative effect.

Distal Exposure

Retroclavicular exposure is rarely performed in isolation, as we perform the supraclavicular approach and supplement with infraclavicular dissection, as necessary. It will be required for lower trunk access such as during coaptation with the contralateral C7. Options include inferior traction on the clavicle, with a retractor or loop of umbilical tape placed around the clavicle on which to pull. Sometimes, there is an established nonunion through which to operate, otherwise osteotomy can be performed after preplating. Exposure here will require division of subclavius muscle and suprascapular vessels.

Infraclavicular exposure is traditionally accomplished through a deltopectoral groove approach, which we modify with a "Z" in the axilla (►**Fig. 6**). The pectoralis major is divided in a Z-fashion and later repaired. The coracobrachialis and biceps short head will then be appreciated. The pectoralis minor is divided, as it directly overlies the plexus. The lateral cord will be the most superficial structure at this level. Dissection should take place lateral to the cords to avoid injury to the pectoral nerves. Prior to the lateral cord terminating as the musculocutaneous nerve, its lateral contribution to the median nerve will branch off its medial side, providing the median nerve's sensory component and proximal motor innervation. By definition, the medial cord is medial to the axillary artery and slightly posterior as well. It branches medially into the ulnar nerve and laterally into the contribution to the median nerve, providing the C8 and T1 motor fibers for the median-innervated intrinsics. These branches form an "M" shape classically (►**Fig. 7**); however, variations are common. One study demonstrated the lateral cord to contribute to the ulnar nerve in 43%.

Fig. 6 Skin markings for infraclavicular plexus exploration seen along with the necklace incision utilized for supraclavicular exposure.

The axillary and radial nerve branches are explored lateral to the axillary artery, where they may originate from the posterior cord or, in the 20% in whom this cord absent, directly from the plexus. External rotation of the humerus will make the axillary nerve more identifiable in the quadrilateral space (►**Fig. 8**). The radial nerve is the largest nerve in the plexus, often carrying fibers from C5-T1. It travels on the lower edge of the conjoint tendon of the teres major and latissimus dorsi (LD), behind the median nerve. This dissection allows an all-anterior approach for quadruple nerve transfer (spinal accessory to suprascapular, radial to axillary, and double Oberlin), which we utilize when we are confident about the triceps strength, such that harvest of a motor branch will be well-tolerated without a significant donor deficit of elbow extension.

The teres major tendon is an important landmark for this transfer, where the axillary nerve can be identified on its upper border and the motor branch to the long head of the triceps on its lower border. At this point it is worth remembering that the axillary nerve is coursing from the superomedial aspect of the quadrangular space and descending posteriorly and laterally to supply the deltoid from posterior to anterior. Hence, one should dissect the axillary nerve out medially and divide it as proximal as possible for direct coaptation with the triceps motor branch. The axillary nerve divides into two branches as it enters the quadrangular space. Two ways to identify the branches is that the portion closer to the humerus supplies the anterior deltoid and this is the thicker of the two. If isolated transfer to the anterior division is planned, one can perform internal neurolysis of the undivided nerve. Otherwise, transfer to the entire trunk can be performed.

If triceps strength is questionable, we then perform a posterior approach to allow stimulation of multiple radial nerve branches prior to harvesting one as a donor. The posterior approach is beyond the scope of this article, but it is well described by Somsak et al.

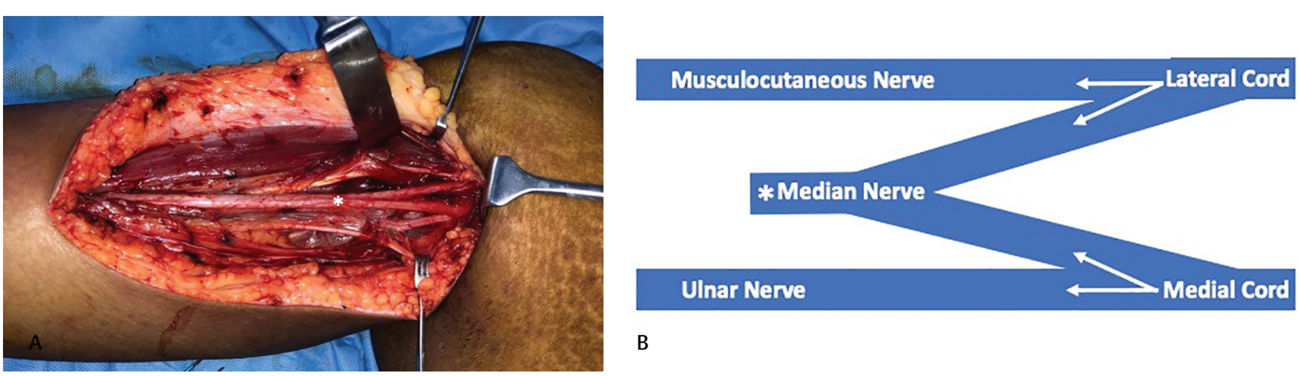

Fig. 7 (**A**) Infraclavicular exposure demonstrates the terminal branches of the plexus, with the asterisk denoting the median nerve. (**B**) The sideways "M" formed by the medial and lateral cords is conceptualized.

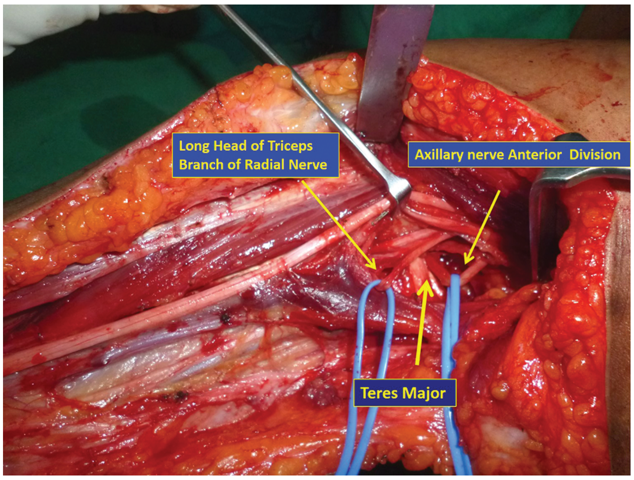

Fig. 8 The axillary nerve in the quadrilateral space is visualized from the anterior infraclavicular exposure.

Complications

The surrounding nervous, vascular, and lymphatic structures are at risk during dissection, especially in the setting of distortion and scarring from trauma. Superficially, the supraclavicular nerve branches can form bothersome neuromas if they are cut or excessively tractioned. During lower root/trunk exploration, the vertebral artery and subclavian vessels are at risk, especially after injury when fibrosis is present. The phrenic nerve can be injured during dissection over the anterior scalene or from traction alone, which will impact respiration to varying degrees, more so on the right side where it is generally dominant.[7] For this reason, we do not mobilize the phrenic nerve or explore the roots medial to it. On the left side, the thoracic duct can be injured, which can lead to a chylothorax or lymphocutaneous fistula. Traction on avulsed nerve roots that rest within the vertebral foramina may cause cerebrospinal fluid (CSF) leak through a pseudomeningocele, although typically not to a large degree. The IJV is at risk medially from sharp laceration or prolonged retraction. The transverse cervical and suprascapular arteries arising from thyrocervical trunk and the dorsal scapular artery over the C8 root can cause bleeding if not appropriately protected or ligated. The lower roots surround the first rib, and exploration without adequate visualization risks damage to the pleura. The subclavian artery is located inferiorly within the interscalene triangle, while the vein is located anterior to the anterior scalene. Both subclavian vessels are at risk with inferior traction or periclavicular dissection. In the infraclavicular exploration, one needs to be cognizant of associated vascular injury, making the dissection through fibrosed tissue around the axillary vessels tedious. With extensive knowledge of anatomy, however, this can be done safely. With advances in nerve transfer surgery over the past few decades, surgery of the brachial plexus has undergone a paradigm shift to the increasing benefit of our patients.

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Conflict of Interest
None declared.

References

1 Gilbert A, Brachial Plexus Injuries. London: Martin Dunitz Ltd; 2001
2 van der Werken C, de Vries LS. Brachial plexus injury in multitraumatized patients. Clin Neurol Neurosurg 1993;95(Suppl): S30–S32
3 Jain DKA, Bhardwaj P, Venkataramani H, Sabapathy SR. An epidemiological study of traumatic brachial plexus injury patients treated at an Indian centre. Indian J Plast Surg 2012;45(3):498–503
4 Grossman JAI, Price A, Chim H. Complications in surgery for brachial plexus birth injury: avoidance and treatment. J Hand Surg Am 2018;43(2):164–172
5 Justice D, Awori J, Carlson S, Chang KW-C, Yang LJ-S. Use of neuromuscular electrical stimulation in the treatment of neonatal brachial plexus palsy: a literature review. Open J Occup Ther 2018;6(3)
6 Kierner AC, Zelenka I, Heller S, Burian M. Surgical anatomy of the spinal accessory nerve and the trapezius branches of the cervical plexus. Arch Surg 2000;135(12):1428–1431

Note: References 7-21 are available online.

