Anatomy of the brachial plexus and its implications for daily clinical practice: regional anesthesia is applied anatomy

Georg C Feigl,[1] Rainer J Litz,[2] Peter Marhofer [3]

[1]Macroscopic and Clinical Anatomy, Gottfried Schatz Research Center, Medical University of Graz, Graz, Austria
[2]Anesthesiology, Intensive Care Medicine and Pain Therapy, Hessing Stiftung, Augsburg, Germany
[3]Anaesthesiology, General Intensive Care Medicine and Pain Therapy, Medical University of Vienna, Vienna, Austria

Correspondence to
Peter Marhofer, Medical University of Vienna, Vienna 1090, Austria; peter.marhofer@meduniwien.ac.at

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ABSTRACT

Safety and effectiveness are mandatory requirements for any technique of regional anesthesia and can only be met by clinicians who appropriately understand all relevant anatomical details. Anatomical texts written for anesthetists may oversimplify the facts, presumably in an effort to reconcile extreme complexity with a need to educate as many users as possible. When it comes to techniques as common as upper-extremity blocks, the need for customized anatomical literature is even greater, particularly because the complex anatomy of the brachial plexus has never been described for anesthetists with a focus placed on regional anesthesia. The authors have undertaken to close this gap by compiling a structured overview that is clinically oriented and tailored to the needs of regional anesthesia. They describe the anatomy of the brachial plexus (ventral rami, trunks, divisions, cords, and nerves) in relation to the topographical regions used for access (interscalene gap, posterior triangle of the neck, infraclavicular fossa, and axillary fossa) and discuss the (interscalene, supraclavicular, infraclavicular, and axillary) block procedures associated with these access regions. They indicate allowances to be made for anatomical variations and the topography of fascial anatomy, give recommendations for ultrasound imaging and needle guidance, and explain the risks of excessive volumes and misdirected spreading of local anesthetics in various anatomical contexts. It is hoped that clinicians will find this article to be a useful reference for decision-making, enabling them to select the most appropriate regional anesthetic technique in any given situation, and to correctly judge the risks involved, whenever they prepare patients for a specific upper-limb surgical procedure.

INTRODUCTION

The field of topographical anatomy is complex and there is likely an educational need to summarize anatomical concepts to support high-quality regional anesthesia.

In the literature, anatomical oversimplifications may be misleading. One example would be the concept of a "brachial plexus sheath"[1 2] with its derivative misconceptions like "extrafascial" and "intrafascial" injections[3 4]or "outside versus inside" injections.[5] Further, it is unclear if the establishment of ultrasound in daily clinical practice has improved anesthetists' understanding of topographical anatomy.

Appropriate anatomical descriptions are particularly required to optimize the safety and efficacy of techniques used as widely as upper-limb blocks. The present article was designed to close the gap between oversimplification and an adequate anatomical description by providing a structured overview that is clinically oriented and tailored to the needs of regional anesthesia.

TOPOGRAPHICAL ANATOMY OF THE BRACHIAL PLEXUS

The brachial plexus, being the main innervator of the upper limb, is generally formed by the ventral rami of spinal nerves of the spinal cord segments C5 to T1.[6 7] Additional fibers may contribute to the nerve supply from one more cranial or up to two caudal level(s) (C4 or T2,3).[8 9]These anatomical variants, referred to as prefixed or postfixed, are clinically relevant to how the shoulder (C4) and medial arm (T2 or even T3) regions are innervated.[10 11] The descriptions in anesthesia literature tend to summarize "one type" of brachial plexus anatomy, not taking into consideration its anatomical variants.[12 13] Along its course from proximal to distal, the brachial plexus passes through four distinct topographical areas: interscalene gap, posterior triangle of neck, infraclavicular fossa, and axillary fossa.[14] This anatomical nomenclature is evidently different from anesthesiologists' terminology but offers a more precise basis for better orientation.

Interscalene gap

This is a very narrow area bounded ventrally by the anterior and dorsally by the middle scalene muscles.[14] It continues the epidural space laterally, is filled by loose fat and connective tissue, and accommodates the ventral rami of spinal nerves C5 to T1. In this way, local anesthetic may spread into the epidural space during plexus blockade via the interscalene route.[15–17] Each ventral ramus is surrounded by the epineural sheath, which contains more or less substantial amounts of fatty tissue. The tissue around the ventral rami is filled with fat and loose connective tissue without a sheath (figure 1).

The prevertebral fascia[18 19] covers both the local nerve structures and the prevertebral (long muscle of the neck and scalene) muscles; overall, it covers the brachial plexus and the subclavian artery until the lateral margin of the interscalene gap and the phrenic nerve. The latter originates in the C4 segment, takes a convex course passing the C5 ventral ramus at a short distance and, still covered by the prevertebral fascia, descends on the ventral

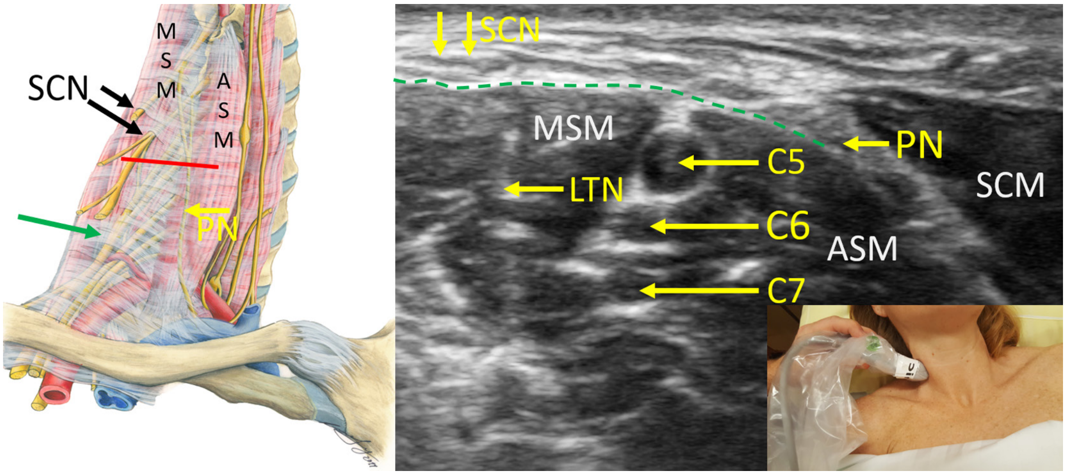

Figure 1 Anatomy of the interscalene gap, including an ultrasound cross-section at the level of the C6 vertebra. The ultrasound probe is indicated by the red line and the prevertebral fascia by the green line (ultrasound image) and green arrow (anatomical illustration). ASM, anterior scalene muscle; LTN, long thoracic nerve; MSM, middle scalene muscle; PN, phrenic nerve; SCM, sternocleidomastoid muscle; SCN, supraclavicular nerves.

surface of the anterior scalene muscle. Caudally, where the ventral branches of C8 and T1 pass through, the interscalene gap widens, and the nerve structures closely approach the subclavian artery and the body of the first rib in this anatomical region.

Winnie *et al*[2] count among the study groups who interpreted the prevertebral fascia as a "brachial plexus sheath." But the existence of this sheath has never been confirmed by macroscopic anatomical evidence nor in anatomical textbooks. The fact that its existence was generally accepted did result in definitions for needle positioning inside ("intrafascial") or outside ("extrafascial") of this sheath. What has become known as "extrafascial" needle positioning, going by the definition of Albrecht *et al*,[20] more or less coincides with the middle scalene muscle, hence being tantamount to intramuscular injection and limiting any medial and ventral spread to the anterior scalene muscle, as the middle scalene muscle has a thin muscular fascia of its own. It is this fascia which presumably has been misinterpreted as a sheath surrounding the brachial plexus.

Two anatomically distinct spaces are contained in the interscalene gap: laterally the prevertebral space and medially the scalenovertebral triangle. The latter, bounded laterally by the anterior scalene muscle and medially by the long muscle of the neck, connects the prevertebral space to a ventrally located space without the prevertebral fascia.[21]As a result, any large volumes of local anesthetic used for interscalene brachial plexus blockade might spread in medial directions inside a space filled with loose connective tissue, thus potentially leading to blockade of the recurrent laryngeal nerve, the sympathetic chain, or autonomic innervation systems of the heart.

Posterior triangle of the neck

The supraclavicular area is where the ventral rami of the brachial plexus merge into trunks, the ventral branches of C5/C6 continuing as superior, C7 as middle, and C8/T1 as inferior trunk. Cranially, the brachial plexus is close to the skin surface (1 cm in slim patients). The posterior triangle of the neck is bounded anteriorly (or medially) by the posterior border of the sternocleidomastoid muscle, posteriorly (or laterally) by the anterior border of the trapezius muscle, and caudally by the clavicle. The nerve structures have a mediocaudal position in this region, still covered by the prevertebral fascia, which will fuse with the fascia of the subclavius muscle at the level of the clavicle. The long thoracic and the dorsal scapular nerves form two branches descending directly from the ventral rami of C5 to C7 (C8 being included in 8% of cases) and entering the region of the posterior triangle after piercing the middle scalene muscle. Both of these branches are located dorsal to the brachial plexus and innervate muscles of the laterodorsal thoracic wall (figure 2).[14]

The trunks are highly relevant for their topographical relationships to the subclavian artery. While the course of the superior and middle trunks is cranial to the artery, transitioning to a more lateral direction at the caudal level, the inferior trunk can be found dorsal to the artery where the "corner pocket" is located. In fact, connective tissue layers, possibly in continuation of the Zuckerkandl-Sebileau ligaments, may even separate the inferior trunk from the middle and superior trunks.[14]

Two more branches emerge from the brachial plexus almost at the level of the clavicle: the suprascapular and the subclavian nerves. Being the most lateral nerve in this region, the suprascapular nerve is clearly visible by ultrasound along its lateral course parallel to the clavicle. It passes the scapular notch below the superior transverse ligament where the suprascapular artery (originating in the thyrocervical trunk, a branch of the subclavian artery) can normally be coursed above the ligament. It supplies branches to the supraspinatus/infraspinatus muscles and sensory fibers to the acromioclavicular and glenohumeral (shoulder) joints (see below). The subclavian nerve has its origin cranial to the clavicle and spreads out in a dorsal direction to innervate the subclavius muscle and to supply the periosteum of the medial and middle part of the clavicle, lateral to the insertion area of the coracoclavicular ligament.

A dorsal scapular artery is rather common and can be readily visualized by ultrasound between the trunks of the brachial plexus (figure 3), emerging from the subclavian artery in 75% or from the transverse cervical artery in 25% of cases.[22] At the level of the clavicle or slightly underneath, the trunks continue to split into a lateral, medial, and posterior cord. The lateral cord emerges cranial to the subclavian artery from the ventral divisions of the superior/middle trunk; the medial cord directly dorsal to the artery from the ventral division of the inferior trunk; and the posterior cord dorsocranial to the artery from all dorsal divisions.

Supraclavicular nerves, originating mainly from the C4 ventral ramus, extend caudally to below the prevertebral fascia, piercing

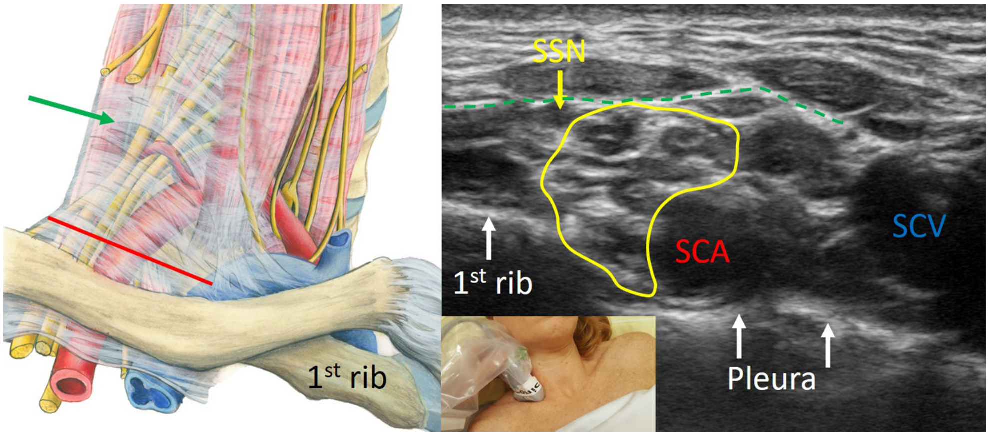

Figure 2 Anatomy of the supraclavicular region including an ultrasound cross-section with an almost vertically directed probe (indicated as red line in the anatomical illustration). The brachial plexus (at the level of the trunks) in the ultrasound image is encircled by the yellow line and the green line indicates the prevertebral fascia. SCA, subclavian artery; SCV, subclavian vein; SSN, suprascapular nerve.

it approximately 2 cm inferior to where the greater auricular nerve winds around the sternocleidomastoid muscle. Erb's point (a term that has been historically handed down, also known as "nerve areal of the neck") is located on the dorsal border of the sternocleidomastoid muscle, where the greater auricular and transverse cervical nerves are seen to wind around, and pierce, the superficial cervical fascia. More aptly, we should speak of a region, since the nerves wind around the muscle at some distance from each other.

The supraclavicular nerve trunk pierces the prevertebral fascia in the cranial part. This main trunk splits into a medial, intermediate, and lateral branch. In the posterior-triangle-of-neck area, they are interposed between the prevertebral and the superficial cervical fascia, then piercing the latter near the clavicle to innervate the skin of the pectoral region overlying the greater pectoral muscle and partially extending to the level of the mamilla. Also, the supraclavicular nerves innervate the ventral, lateral, and dorsal shoulder regions, the clavicular periosteum, the acromion, and the scapular spine.

Infraclavicular fossa

Also known as Mohrenheim's fossa, this space is bounded by the clavicle, the deltoid muscle, the pectoralis major, the upper part of the thorax, and the medioclavicular line.[6 14] The clavipectoral fascia, continuing the prevertebral fascia laterally with connections to the fascia of the subclavius muscle, divides this space into a superficial and a deep layer. It is pierced by the cephalic vein, which drains the subclavian vein and is the most lateral structure of this deep layer of the infraclavicular fossa. Also visible in this anatomical region is the thoracoacromial artery, which originates from the subclavian artery. Finally, the lateral and, in rare cases, medial pectoral nerves are located superficially to innervate the pectoralis major and minor muscles, the former arising from the lateral cord and the latter from the medial cord of the brachial plexus almost at the entrance to the axillary fossa (figure 4).

The lateral cord of the brachial plexus is the most superficial nerve structure in the deep layer of the infraclavicular fossa, being located lateroventral to the subclavian artery, as compared with a dorsolateral relative position of the posterior cord and a dorsal position of the medial cord. Behind the pectoralis minor, this configuration changes to an arrangement of pronation-style winding of all three cords around the artery. Given a high prevalence of variation,[23] ultrasound imaging may occasionally display more than three nerve structures due to splitting of cords or trunks. Visualization of three nerve structures would certainly be the norm, but the number of structures on display may change as cords are missing or undergoing division in the infraclavicular region already.

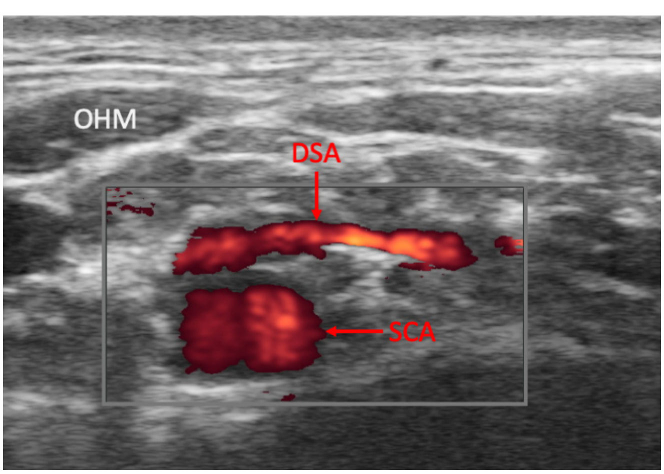

Figure 3 Ultrasound image of the supraclavicular region of the brachial plexus. The large dorsal scapular artery (DSA) is cleary visible in the color Doppler mode above the subclavian artery (SCA). OHM, omohyoid muscle; left side, medial.

Axillary fossa

This space resembles a pyramid whose apex is the coracoid process and whose base is the superficial axillary fascia, the latter being a cribriform structure pierced by the intercostobrachial nerve.[14] Furthermore, the pyramid has dorsal, medial, and ventral walls consisting of the subscapular muscle with its fascia, the serratus anterior muscle with its fascia, and the greater pectoral muscle, respectively.[14] Nerve structures enter the axillary fossa underneath the deep axillary fascia, which is the continuation of the clavipectoral fascia (figure 5).

Hence, the major neurovascular structures are located in what is known as the "deep axillary space," which is a continuation of the deep layer of the infraclavicular fossa, underlying the clavipectoral and prevertebral fasciae in the posterior triangle of neck. The deep axillary fascia separates the deep axillary space (lateral) from the subfascial axillary space (medial), the latter being crossed from medial to lateral by the intercostobrachial and thoracodorsal nerves. The long thoracic nerve, covered by

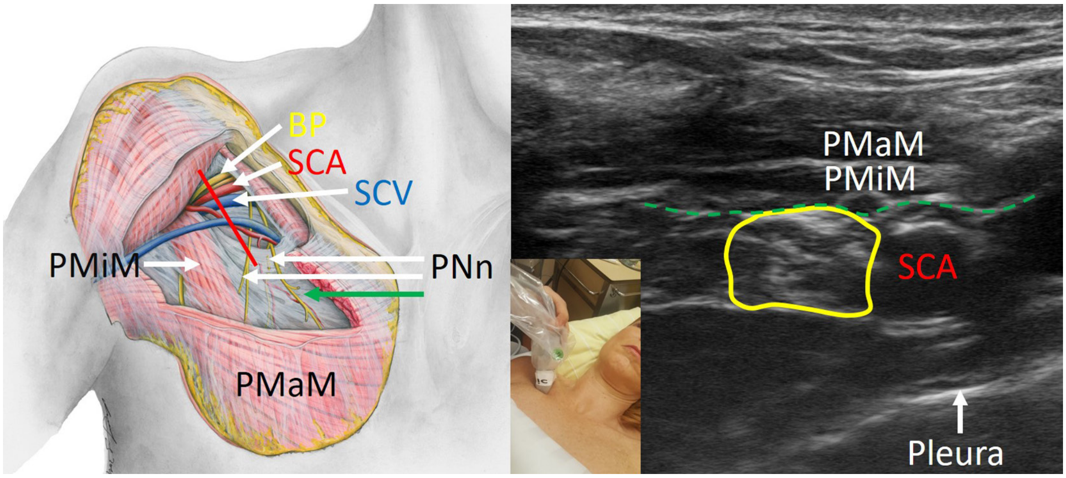

Figure 4 Anatomy of the infraclavicular region including an ultrasound cross-section. The position of the ultrasound probe is indicated by the red line. The brachial plexus (at the level of the cords) in the ultrasound image is encircled by the yellow line and the clavipectoral fascia is indicated by the green line. BP, brachial plexus; PMaM, pectoralis major muscle; PMiM, pectoralis minor muscle; PNn, pectoral nerves; SCA, subclavian artery; SCV, subclavian vein.

the fascia of the serratus anterior muscle, passes medially along the thoracic wall. The main cords of the brachial plexus are located inside the deep axillary space and divide or split into the well-known branches extending into the upper limb.

Lateral cord

Being the first branch emerging from the lateral cord, the musculocutaneous nerve is subject to considerable variability, usually arises dorsal to the pectoralis minor muscle, and often enters the coracobrachialis muscle as one main stem. The medial portion of the lateral cord forms the lateral root of the median nerve, which merges with the medial root arising from the medial cord. The union of the roots is usually seen in a ventral, but sometimes indeed in a dorsal, position relative to the axillary artery.[13]

Medial cord

The medial root of the median nerve runs in a lateral direction to merge with the lateral root. The two medial cutaneous nerves of arm and forearm occupy a more superficial position than the ulnar nerve, which is the main branch of the medial cord. Several branches of the medial cutaneous nerve of arm cross the subfascial axillary space and pierce the superficial axillary fascia at the level of the latissimus dorsi muscle to connect with fibers of the intercostobrachial nerve. The medial cutaneous nerve of forearm, being the largest purely sensory nerve in this area, perforates the superficial brachial fascia at the hiatus basilicus. The ulnar nerve starts out medial to the axillary artery, following a dorsal orientation along its distal course and perforating the medial intermuscular septum to enter the compartment of the arm's extensor muscles.

Posterior cord

The main branches of this cord are the radial and axillary nerves, the latter being located deeper and extending distally from the entrance of the axillary fossa, where it descends from the cord, to the ventral surface of the subscapular muscle. Then, it takes a lateral and dorsal turn to pass the quadrangular space (also known as quadrilateral space or lateral axillary hiatus) towards

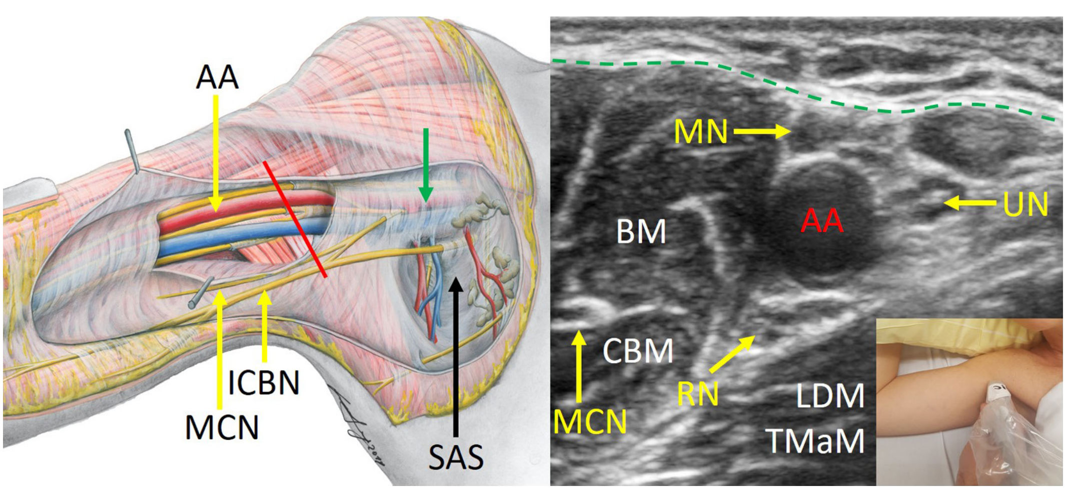

Figure 5 Anatomy of the axillary region including an ultrasound cross-section. The position of the ultrasound probe is indicated by the red line. The green line in the ultrasound image and the green arrow in the anatomical illustration indicate the deep axillary fascia. AA, axillary artery; BM, biceps muscle (short head); CBM, coracobrachial muscle; ICBN, intercostobrachial nerve; LDM, latissimus dorsi muscle; MCN, musculocutaneous nerve; MN, median nerve; RN, radial nerve; SAS, subfascial axillary space; TMaM, teres major muscle; UN, ulnar nerve.

innervating the deltoideus and teres minor muscles. Occasionally, the axillary nerve is covered by fibers of the subscapular muscle. Its sensory fibers continue to form the superior lateral cutaneous nerve of arm, innervating a skin area of the dorsal proximal arm, the shoulder region of the deltoid muscle, and the dorsal capsule of the shoulder joint. In most cases, the nerve will be accompanied by the posterior humeral circumflex artery.

The radial nerve is located deep to the axillary/brachial artery and superficial to the tendon of the latissimus dorsi muscle. It takes a lateral turn and, accompanied by the deep brachial artery, crosses the humerus from dorsal between the medial and lateral heads of the triceps brachii muscle. Subscapular branches arise in the proximal area of the posterior cord to innervate the subscapular muscle and the ventral capsule of the shoulder joint. Another structure arising from the posterior cord is the thoracodorsal nerve, one branch going to the subscapular muscle and the main trunk to the latissimus dorsi and teres major muscles, accompanied by the thoracodorsal artery.

As documented by Rorie,[24] the entire arrangement of nerve structures in the infraclavicular and axillary region, including splitting and branching, also causes the epineural sheaths to split. The septa and the sheaths surrounding each nerve have a barrier function, enabling the nerves to run through their own fascial tunnels.

ANATOMICALLY ORIENTED APPROACHES TO THE BRACHIAL PLEXUS

A number of approaches are available for brachial plexus blockade, and the clinical indications for each of them, being dictated by anatomical considerations, differ considerably. The upper-arm and shoulder regions are supplied both from the brachial plexus and also from the cervical plexus (supraclavicular nerves) and from the thoracic spinal nerves (intercostobrachial nerve, direct branches). Regional anesthesia performed above the clavicle will block either the ventral rami of the spinal nerves or, where the trunks have formed, any branched-off terminal nerves like the long thoracic nerve or the dorsal scapular nerve. Techniques performed below the clavicle will mainly block fascicles (infraclavicular approach) or any of the terminal nerves (axillary approach). “Plexus block” is therefore, strictly speaking, really a misnomer in the axillary position because what is really blocked here is a combination of single nerves.

Interscalene brachial plexus blockade

The main indication for this technique is shoulder surgery, which requires blockade of the suprascapular, lateral pectoral, musculocutaneous, and axillary nerves of the brachial plexus and the C4 supraclavicular nerves of the cervical plexus. This can be accomplished at the level of the interscalene gap, as the suprascapular nerve exits the brachial plexus in the posterior-triangle-of-neck area, thus possibly necessitating an extra block when a supraclavicular approach is used for shoulder surgery (see next section). The interscalene approach blocks the suprascapular nerve at its superior-trunk exit from C5, the lateral pectoral and musculocutaneous nerves at their respective lateral-cord exits from C5 to C7, and the axillary nerve at its posterior-cord exit from C5 to C8. It is vital to understand that this large space of administration will allow any major volumes of local anesthetics to spread diffusely inside the epidural space and that medial spread might occur, as the prevertebral space offers a very limited volume. Franco and Williams indicate also the danger of a neuraxial spread of the local anesthetics (figure 1).[25]

A lateromedial direction of the needle will add to this risk, whereas a mediolateral orientation will direct the spread laterally and enable coverage of the suprascapular nerve by the local anesthetic. At any rate, separate blockade of the supraclavicular nerves is required, as these are located superficial to the prevertebral fascia at the level of interscalene or supraclavicular blocks. We favor an out-of-plane approach for ultrasound-guided interscalene blockade of the brachial plexus.[26] The rationale is anatomical, as a laterodorsal in-plane approach can possibly traumatize the long thoracic and dorsal scapular nerves, which pierce the middle scalene muscle.[27 28] Injury of the long thoracic nerve will result in paralysis of the anterior serratus muscle, the consequence being a winged scapula (scapula alata). Lesions of the dorsal scapular nerve, in turn, lead to paralysis of the levator scapulae and rhomboid muscles, thus also winging the scapula and impairing the ability to elevate the arm above the horizontal.

A major complication of interscalene brachial plexus blocks is accidental blockade of the phrenic nerve leading to hemidiaphragmatic paresis.[29 30] The phrenic nerve usually originates from the C4 segment, but the C3 and C5 segments (the latter being clinically more relevant) may contribute nerve fibers. The phrenic nerve is commonly seen to start out by a laterally convex curvature, then crossing the C5 and C6 ventral branches before changing from a medial to a caudal direction. Farther caudally, it is located ventral to the anterior scalene muscle. Low doses of local anesthetic (<10 mL) may prevent the phrenic nerve from being inadvertently blocked. Large volumes can also block the ipsilateral[31 32] or the contralateral[33]recurrent laryngeal nerve or the sympathetic chain.[34]

Falyar *et al*[35] reported that blocking the C5 segment, about 4 cm cranial to a regular interscalene plexus block, invariably caused staining of the phrenic nerve and even additional epidural spreading. A recent cadaver study suggests that the phrenic nerve can potentially be spared by using a technique with 5 mL of local anesthetic.[36] However, in this study, the phrenic nerve took a medial turn cranial to C5, whereas a non-variant anatomical course would likely have resulted in staining. We routinely identify and trace the phrenic nerve at this level and to apply the block at a more caudal level if appropriate.

Anatomical variations of the nerve structures are common. One example would be dislocation of the C5 ventral ramus from other ventral rami, so that it may supposedly be found anterior to the anterior scalene muscle (figure 6). It is not uncommon to see the very existence of an interscalene gap challenged by the presence of muscular bridges between the anterior and middle scalene muscles (figure 7). Other muscular variations may be present in the form of connections between the superficial and deep muscle layers (cleidoatlanticus,[37] scalenus minimus, cleidoaxialis,[38] and costopleurovertebral ligament).[39 40] Any of these variations will affect ultrasound imaging, which may give rise to confusion against previous images that reflected normal anatomical relationships. A dorsal scapular artery may arise in a very medial position from the subclavian artery and may ascend between the ventral rami of the spinal nerves to cross the interscalene gap, which is usually visible in ultrasound and can be safely protected during regional anesthesia (figure 3). What should also be considered during out-of-plane needle guidance is the possibility that, especially in slim patients, the vertebral artery may be very superficial.

Supraclavicular brachial plexus blockade

This technique can be used to cover the entire upper limb, the only exception being the medial brachial area, which is covered

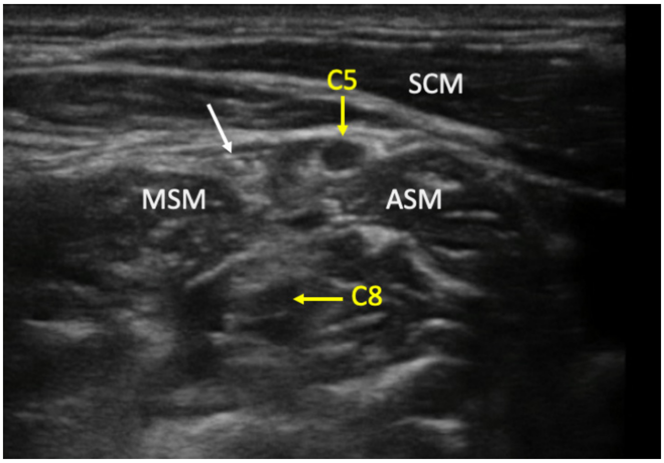

Figure 6 Ultrasound image of the interscalene gap (indicated by the white oblique arrow). The ventral ramus of the C5 nerve root is clearly visible anterior to the anterior scalene muscle (ASM). The ventral rami of the C6 and C7 roots are not visible in this plane. MSM, middle scalene muscle; SCM, sternocleidomastoid muscle; right side, medial.

by the intercostobrachial nerve. For shoulder surgery, additional blockade of the suprascapular nerve may be needed. It is important to understand that these blocks will not cover the axilla and the medial part of the upper arm. Anatomically, the indications will ideally range from hand to elbow: the median, radial, and ulnar nerves need to be blocked for wrist surgery, while elbow surgery requires additional blockade of the musculocutaneous nerve and potentially of the intercostobrachial nerve. Several anatomical variations need to be considered,[41] although the possibilities may not be fully understood at present (figure 2).

A supraclavicular block can cover all nerves of the brachial plexus. Local anesthetics administered in this way routinely cover the superior and the middle trunk with its branches (ie, the suprascapular and subclavian nerves). Their spread may not reach the inferior trunk and the two separate nerves dorsal to the plexus (the long thoracic and dorsal scapular nerves should not be blocked), possibly due to the continued fixation ligaments of the pleura known as Zuckerkandl-Sebileau ligaments. These ligaments, and notably the costopleurovertebral ligament, form a fascial plane separating the inferior trunk from the middle and superior trunks. Nevertheless, like all fascial planes, also the costopleurovertebral ligament is a permeable structure and may enable a diffusion of local anesthetic and a subsequent blockade of the inferior trunk. In-plane guidance with a lateromedial needle direction is suitable for this type of blockade. Since this orientation of the needle is able to achieve a medial (and subsequently central) spread, care should be taken to reasonably minimize the administered volume. To avoid injury to the pleura, adequate sonographic visibility of the needle tip must be ensured. Low-volume injection in a lateromedial direction can affect the phrenic nerve but spare the inferior trunk.[42]

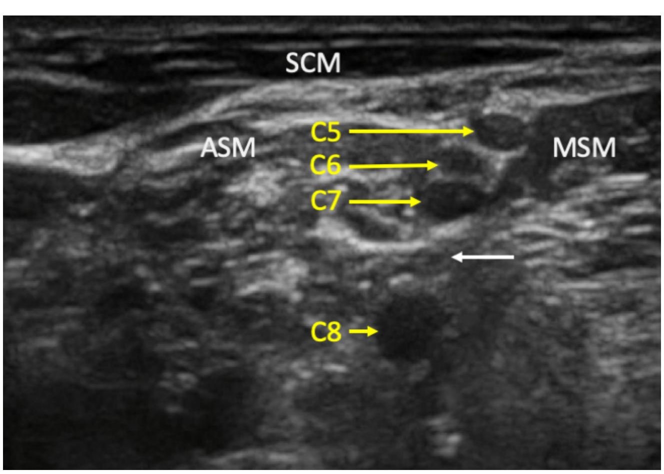

Figure 7 Ultrasound image of the interscalene gap. A muscle bridge (indicated by the white arrow) sperates the C7 from the C8 ventral rami. ASM, anterior scalene muscle; MSM, middle scalene muscle; SCM, sternocleidomastoid muscle.

Each branching of cords at periclavicular levels involves an epineural sheath division, and any connections between these sheaths and dense walls of connective tissue can unpredictably separate trunks, cords, and proximal peripheral nerves in fascial tunnels. Anatomical configurations of this type can make a difference to how a brachial plexus block is executed, in that multiple administrations of local anesthetic may be required as increasingly distal approaches at periclavicular levels will increase the risk of localized, and hence inadequate, spreading inside these fascial tunnels. Another anatomical variation concerns the dorsal scapular artery, which pierces the posterior triangle of neck in around 40% of cases. Thus, careful assessment by ultrasound is recommended to identify and avoid accidental puncture of this, more often than not prominent, vessel.

Infraclavicular brachial plexus blockade

This approach can be used for surgery performed on the elbow or more distal regions. Shoulder surgery is not an indication. Some nerves often remain unblocked by this procedure, including the medial cord and the intercostobrachial nerve. Such lack of blockade has been attributed to the presence of developed septa inhibiting a dorsal and medial spread around the subclavian or axillary artery.[43] These septa and divisions of epineural sheaths account for better results of double compared with single injections for costoclavicular blocks applied via the proximal infraclavicular fossa. Hence, the notion of blocking all (ie, even more than three) nerve structures visible in the ultrasound image is being discussed for a reason.[44] Infraclavicular brachial plexus blockade in children provide more complete blocks, which could be explained by an incomplete maturation of fascial layers (figure 4).[45]

The beforementioned limitations also explain why the infraclavicular approach has the narrowest spectrum of indications among the various possibilities of brachial plexus blockade. In a cranial direction, the deep layer of the infraclavicular fossa is continuous with the prevertebral space and will end up connecting to the epidural space. It is therefore crucial to understand that significant volumes of local anesthetic spreading upwards might reach the interscalene gap, causing blockade of the sympathetic chain.[46 47]Despite convential wisdom, it is possible to block the phrenic nerve as well. Given a more medial direction of spread, a substantial volume of local anesthetic may reach the epidural space and block the cervical spinal cord.

Respiratory impairment or failure following an infraclavicular procedure may be caused by blockade of the phrenic nerve or by epidural spread of the local anesthetic.[48] The risk of phrenic nerve involvement has been found to decrease progressively at more caudal levels, although the 20 mL volumes used still caused ≈ 5% of phrenic nerve involvement in costoclavicular blocks.[49] Injection close to the posterior cord might cause the volume to

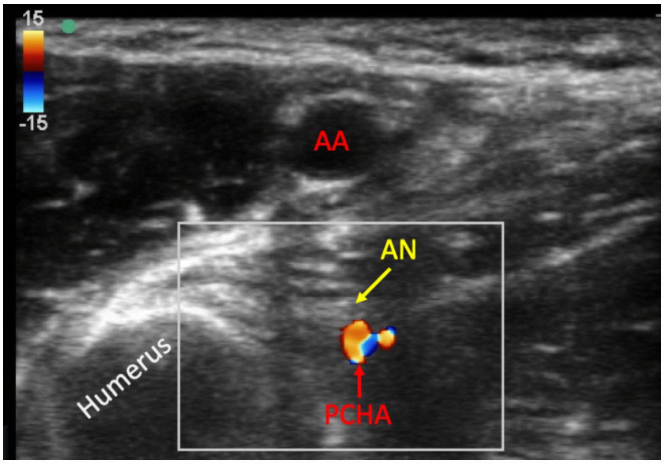

Figure 8 Ultrasound image of the axillary nerve (AN) in close relationship to the posterior circumflex humeral artery (PCHA) in the axillary region. AA, axillary artery; left side, cranial.

spread into the thoracoscapular space of loose connective tissue between the scapula and the subscapular (dorsal) and anterior serratus (ventral) muscles. This tiny space may feature an extension which potentially can take up a considerable volume. The medial cord may be visualized as forming one cord with the lateral or the posterior cord. One single cord instead of three has also been reported, and the positions of the three cords relative to the artery are extremely variable.

Axillary brachial plexus blockade

An axillary brachial plexus approach is characterized by combinations of individual nerve blocks, which implies that the indications for axillary brachial plexus blockade can be precisely customized to the prospective surgical site. The individual nerves vary in the positions they occupy relative to the axillary artery. Typically, the musculocutaneous nerve is located behind or within the coracobrachialis muscle, or between this muscle and the short head of the biceps muscle, but it may also be found very close to the median nerve. Sometimes, the nerve arises from the median nerve at a very late point, just proximal to the cubital region, before its continuation as lateral cutaneous antebrachial nerve. We recommend making sure that this nerve is correctly identified to guard against unwelcome surprises, given its high prevalence of variations (figure 5).

The axillary nerve can be blocked, if indicated, where it joins the posterior humeral circumflex artery and intercostobrachial nerve (figure 8).[50] The nerve structures of the brachial plexus are divided by septa and run through fascial tunnels in the deep axillary space.[51]

It is therefore recommended to employ almost single-shot techniques to get efficient results; this is not a new recommendation but one that always warrants a reminder. Taking a ventral approach, the axillary nerve can be blocked, if indicated, at the level of the quadrangular space where it joins the posterior humeral circumflex artery. More importantly, this approach can be combined with blockade of the intercostobrachial nerve to bring comprehensive analgesia to all regions of the upper limb.[50]

CONCLUSIONS

For any technique of regional anesthesia, safety and effectiveness are mandatory requirements which can only be met by anesthetists who have appropriate knowledge of the relevant anatomical details. The need for customized anatomical literature to convey this knowledge is particularly great when it comes to techniques as common as blocks for the upper extremity. The present review has been written to address this need. It is hoped that clinicians will find this article to be a useful reference for decision-making, enabling them to select the most appropriate regional anesthetic technique in any given situation, and to correctly judge the risks involved, whenever they prepare patients for a specific procedure of upper-limb surgery.

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ORCID iD
Peter Marhofer http://orcid.org/0000-0002-1647-3780

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