Review article: anatomical considerations for ultrasound guidance for regional anesthesia of the neck and upper limb

Article de synthèse: considérations anatomiques pour l'échoguidage lors de l'anesthésie régionale du cou et des membres supérieurs

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Abstract

Purpose *The purpose of this narrative review is to describe an anatomical approach for residents-in-training and anesthesiologists who are learning techniques of ultrasound-guided regional anesthesia of the neck and upper limb*

Sources *Relevant articles relating anatomy and anatomical variation to the emerging practice of ultrasound-guided regional anesthesia for the neck and upper limb were sourced via both Medline and PubMed databases. Also, our approach to teaching ultrasound technique has developed from using anatomical resources and cadaveric workshops. This approach emphasizes precise image acquisition, a detailed knowledge of anatomy and anatomical variations, and, importantly, visual interpretation of sonographic landmarks based on pattern recognition when interpreting sonograms.*

Principal findings *Typical sonographic patterns orient the examiner to nerve position, which is necessary for executing successful regional anesthesia of the neck and*

upper limb. Only by understanding the typical anatomical arrangement can the examiner then visually interpret any individual anatomical variation that may occur.

Conclusion *Simple sonographic anatomical patterns can provide a strategy to correctly locate nerves when performing ultrasound-guided cervical and brachial plexus anesthesia.*

Résumé

Objectif *L'objectif de ce compte-rendu narratif est de décrire une approche anatomique destinée aux résidents en formation et aux anesthésiologistes qui apprennent les techniques d'anesthésie régionale du cou et des membres supérieurs par échoguidage.*

Sources *Les articles pertinents traitant de l'anatomie et des variations anatomiques dans la pratique émergente de l'anesthésie régionale du cou et des membres supérieurs par échoguidage ont été tirés des bases de données Medline et PubMed. De plus, notre approche de l'enseignement des techniques échoguidées a évolué grâce au recours à des ressources anatomiques et des ateliers sur des cadavres. Cette approche met l'accent sur l'obtention d'images précises, une connaissance détaillée de l'anatomie et des variations anatomiques et, composante importante, l'interprétation visuelle de points de repères échographiques selon une reconnaissance des configurations lors de l'interprétation des échogrammes.*

Constatations principales *Les configurations échographiques typiques fournissent des informations à l'examineur quant à la position des nerfs, ce qui est nécessaire à la réalisation d'une anesthésie régionale du cou et des membres supérieurs réussie. Il faut que l'examineur comprenne la disposition anatomique typique pour ensuite pouvoir interpréter de façon visuelle les variations anatomiques individuelles potentielles.*

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Conclusion *Des configurations anatomiques échographiques simples peuvent constituer une bonne stratégie pour localiser correctement les nerfs lors de la réalisation d'une anesthésie cervicale et du plexus brachial par échoguidage.*

The anesthetist requires a peculiarly specialized knowledge of anatomy. Some regions of the body, for example the respiratory passages, the major veins and peripheral nerves, he must know with an intimate detail which rivals that of the surgeon....

Ellis, *Anatomy for Anesthetists*

The use of ultrasound-guided regional anesthesia is rapidly gaining momentum, and anesthesiologists are becoming more aware of the importance of adopting an anatomically guided approach to major nerve blocks and conduction anesthesia. Well-defined sonographic images of nerves and surrounding tissue formed by the reflection of ultra-high-frequency ultrasound waves are now turning the art of regional anesthesia into science.¹ The ease of accurately performing neural blockade with direct needle visualization, navigation, and targeting of nerves is intuitively appealing. Ultrasound guidance enables needles to be placed next to nerves with less likelihood of eliciting paresthesia or vascular puncture. Outcome studies, though small in number, indicate that this technique is as safe, if not safer, than current techniques of neurolocation.² Ultrasound brings living anatomy to light, and nerves, long hidden beneath the skin surface, are now illuminated. With this application, the appreciation of the human structure is undergoing a renaissance in the specialty of anesthesia.

Knowledge of anatomy is essential in performing regional anesthesia, particularly for ultrasound guidance. Once an image is acquired, the anesthesiologists will only identify what is known, based on knowledge of precise anatomical detail. It is the recognition of visual sonographic patterns or, more precisely, sonographic landmarks that enables correct visual interpretation of the sonogram and the location of nerves. Recognition is significant, since anatomical variation and asymmetry is relatively common, making individual anatomy unique. Novices training in ultrasound guidance need an understanding in anatomy to competently interpret sonograms. Anatomy can be rediscovered through teaching programs,³ which may involve cadaveric dissection, problem-based tutorials, and interactive computer instruction.⁴ Cadaveric models, for example, have been used for practical training in both anatomical dissection and ultrasound needling technique.⁵ However, competency in ultrasound guidance requires an overall stepwise progression of training in sonographic image acquisition, pattern recognition, manual dexterity for needle alignment, advancement, and injection of target nerves.¹

In this article, the sonographic anatomy of the brachial plexus and the adjacent cervical plexus is discussed. This area is not only of special relevance to anesthetic practice, but it has varied anatomical detail, ideal for training in sonographic technique. The brachial plexus innervates the upper limb by distributing spinal nerve root fibres to terminal nerves via specific neural branching (Fig. 1). The plexus travels to the upper limb through distinct anatomical regions, which define the approach for anesthetic blockade (Table 1). For each approach, the anesthesiologist must determine the site of needle puncture, the layers pierced, and the hazards likely to be encountered with needle advancement. Ultrasound provides a real-time anatomical view, which directs the point of needle insertion and navigation, and, importantly, is not reliant on surface landmarks traditionally used for regional approaches. It is imperative to know the typical anatomy of each region and to be aware that variation can occur.⁶ Only by knowing the typical anatomical relation can the examiner advance to a higher level of interpretation when confronted with individual variation. This review is aimed at providing a strategy for identifying typical sonographic patterns from which the trainee can relate when confronted with anatomical variations.

Sonographic examination

The brachial plexus can be examined in a sequential manner starting from the cervical spine to its terminal branches in the arm. High frequency linear probes 10–15 MHz are ideal for maximal resolution, particularly in the neck and axilla where the plexus is superficially located.⁷ However, when the plexus is situated deeper, as in the infraclavicular region or in obese patients, lower frequencies (5–8 MHz) are more appropriate for tissue penetration but have associated less spatial resolution. Broad-beam probes exhibit a range of frequencies (8–13 MHz) and attempt to address this problem by automatically adjusting parameters, such as focal zone and frequency, when adjustments in depth are made. Footprint size and shape also influences the ease of sonographic examination where, for example, large linear probes may be difficult to position behind the clavicle. Curved array probes are also used for cervical spine examination, and Duplex ultrasound of the carotid vessels is usually conducted with 5–7.5 MHz linear transducers. In instances where image quality is less than ideal, recognition of one or more key sonographic landmarks remains crucial for accurate needle navigation.

The plexus is best scanned in the transverse plane with the probe aligned 90° to its direction of travel. Nerve fascicles have a strongly reflective bright circular or oval rim appearance, with the interior of the nerve appearing dark and granular. In the long axis, nerves appear as a band of

Fig. 1 **a** Spinal root fibres are distributed to upper limb terminal nerves by complex branching of the brachial plexus. Spinal nerves originate from the cervical (C₅₋₈) and thoracic (T₁) nerve roots, which merge and divide as they travel to the upper limb to form neural trunks, divisions, cords, and finally terminal nerves, which innervate the arm. Median nerve (C₅₋₈ T₁), ulna nerve (C_{7,8} T₁), radial nerve (C₅₋₈ T₁), and musculocutaneous nerve (C₅₋₇) (Reproduced with permission from Ref.⁴). **b** Branches of the brachial plexus: (1) Dorsal scapular N (from ant ramus C₅); (2) Suprascapular N (from upper trunk); (3) Lateral Pectoral N (from lat cord); (4) Musculocutaneous N; (5) Median N; (6,7) Medial Pectoral N, Medial cutaneous N of arm and of forearm (from medial cord); (8) Ulnar N; (9,10) N to Subscapularis and to Latissimus Dorsi, N to Teres major (from post-cord); (11) Axillary N; (12) Radial N; (13) Long thoracic N (from ant rami C_{5,6,7}) (Reproduced with permission from Ref.⁴). *ant* anterior; *N* nerve; *lat* lateral; *post* posterior

strongly reflective interrupted parallel lines, distinguished from tendons, which have a continuous linear patterned appearance. This linear fascicular pattern is a feature of

larger nerves and is absent in small nerves. It is important to note that not all circular hypoechoic structures seen on transverse scanning are nerves. Interpretation requires not only careful anatomical orientation, but also precise image optimization, the recognition of artifact, and the ability to distinguish nerves from tendons, muscle, and vessels.^{8,9} In some cases, the use of neurostimulation during ultrasound guidance may further aid in defining a sonographic structure as a nerve.

At each anatomical region, the technique of sweeping the ultrasound beam to and fro with gentle probe angulation and tilting will provide a three-dimensional view of anatomical structure. This provides the primary platform for interpreting sonographic images, since identification of key sonographic landmarks orients the examiner to locate nerve position. These structural patterns can be termed key sonographic views, analogous to the approach used in transesophageal examination of the heart, where a series of twenty standard views enable a comprehensive cardiac examination.¹⁰ For the neck and upper limb, ten key views (of the right side) are proposed:

Reference view

The neck is divided into anterior and posterior triangles (Fig. 2). The anterior triangle is located between the sternocleidomastoid muscle, the midline, and the base formed by the body of the mandible and posterior belly of the digastric muscle. The posterior triangle is the interval between the posterior border of the sternocleidomastoid muscle, the trapezius, and the base formed by the middle third of the clavicle. Examination begins with the *carotid view*, which is obtained by placing the probe transversely over the paratracheal groove in the anterior triangle between the cricoid cartilage and the sternocleidomastoid muscle. Identification of the great vessels and thyroid gland is a key reference image from which sequential examination of the neck can be made. The internal jugular vein and the pulsating common carotid artery are identified with the vagus nerve interposed posteriorly (Fig. 3). This view is commonly used to direct cannulation of the internal jugular vein, as well as for initial examination of the common carotid artery and bifurcation when screening for obstructive disease of the vessel. It is also a starting reference point for examination of the cervical and brachial plexus.

Angulation of the probe laterally identifies the curved brightly echogenic appearance of the large C₆ transverse process with its prominent anterior (Chassaignac's) tubercle. The C₆ nerve root can be identified posterolaterally in transverse view emerging between the anterior and posterior tubercles, which have a typical "fishmouth" appearance. The vertebral artery and vein travel within the

Table 1 Correlation of anesthetic approach to anatomy

Region	Anesthetic approach	Neural structure
<i>Posterior triangle of neck</i>		
1. Apex	Sub-atlas	Posterior ramus C ₂
2. Mid level	High interscalene	Anterior ramus C ₅
3. Lower level	Interscalene	Brachial plexus roots and trunks
4. Base	Supraclavicular	Brachial plexus divisions
<i>Upper limb</i>		
1. Apex of axilla	Infraclavicular medial	Brachial plexus cords
2. Mid level of axilla	Infraclavicular lateral	Brachial plexus cords
3. Base of axilla	Axillary	Brachial plexus terminal branches
4. Mid brachial	Mid humeral	Brachial neurovascular bundle
5. Distal brachial	Supracondylar	Median, radial and ulna nerves, LCNF
6. Distal forearm	Wrist	Median, ulnar, superficial radial nerves
7. Distal palm	Digital	Common palmar digital nerves

LCNF lateral cutaneous nerve of forearm

Fig. 2 Cadaveric anatomy of the posterior triangle of the neck: (1) Sternocleidomastoid m; (2) Trapezius m; (3) Omohyoid m; (4) Scalenus medius m; (5) Spinal accessory n; (6) Brachial plexus; (7) Cervical plexus branches; (8) Occipital vein. *m* muscle; *n* nerve)

foramen transversarium medial and posterior to the prominent anterior tubercle. Movement towards the head shows a similar transverse view of C₅, C₄, and C₃ vertebral bodies. At these levels, the vertebral artery can also be seen in long axis by rotating the probe to 90° and placing the probe along a line between the mastoid and the anterior tubercle of the C₆ transverse process. Directing the beam slightly posterior, a long axis view in the anterior–posterior plane of the artery is seen. Sequential examination of C₅ to C₂ transverse processes can be made by moving the probe

cephalad.¹¹ Scanning the vertebral artery in long axis, as it travels through the foramina transversarium perpendicular to the plane of the transverse processes, produces a picket fence like appearance (Fig. 4). Movement of the probe to the level of the atlas beneath the tip of the mastoid process provides a *sub-atlas* view of the C₂ posterior ramus. At C₂, the vertebral artery forms a prominent loop as it initially winds posteriorly over the lateral mass of the atlas with the posterior primary ramus of C₁ sandwiched between bone and artery. The vessel then loops supero-medially to enter the foramen magnum. This arterial loop acts as a sonographic landmark for identifying the C₂ transverse process and the position of the C₂ nerve root immediately inferior and posterior to the artery. The C₂ nerve root emerges between the posterior arch of the atlas and lamina of the axis to form the greater occipital nerve. It travels obliquely within the gutter of the transverse process posterior to the vertebral artery. Similarly, each cervical nerve emerges from above the corresponding vertebral body and runs obliquely within the gutter posterolateral to the vertebral artery (Fig. 4). The C₇ transverse process is often characterized by a prominent posterior tubercle and absent or rudimentary anterior tubercle and may be used to assess cervical nerve root level.¹²

Stellate ganglion block

Stellate ganglion block under ultrasound guidance has recently been described using the carotid view.¹³ The stellate ganglion (the fused inferior cervical and first thoracic ganglia) is commonly injected for the treatment of hydrohidrosis or complex regional pain syndromes of the upper limb. The inferior cervical ganglion and cervical sympathetic chain travel behind the carotid sheath anterior to the prevertebral fascia, the longus colli muscle, and the transverse processes of the C₇ and C₆ vertebra. Traditional

Fig. 3 Transverse sonogram of the anterior triangle of the neck at C₆ showing the reference carotid view. *A* anterior; *P* posterior; *M* medial; *L* lateral

Fig. 4 Longitudinal sonogram of the apex of the posterior triangle showing the sub-atlas view and relation of cervical nerve roots to the vertebral artery. **a** The vertebral artery forms a distinct sonographic loop as it travels posteriorly from C₂ over the lateral mass of the atlas before entering the foramen magnum. **b** Vertebral artery and vein

identified by colour flow Doppler travelling perpendicular to C₃ and C₄ cervical transverse processes. By convention, cephalad is positioned to the left of a sonogram. *PL* posterolateral; *AM* anteromedial; *S* superior; *I* inferior)

landmark techniques use an anterior paratracheal approach at C₆ with palpation of Chassaignac's tubercle in the groove between the trachea and the sternocleidomastoid muscle. Because of variability in the size of C₆ and its relationship to the stellate ganglion and prevertebral fascia, injection at the base of the transverse process where it joins the vertebral body has been recommended.¹⁴

Cervical plexus block

Landmark regional techniques have traditionally performed deep cervical plexus block by locating bone with needle injection and blindly depositing local anesthetic solution adjacent to the C₂–C₄ transverse processes. Ultrasound guidance enables needles to be advanced to cervical nerve position under direct vision. The nerve roots of the cervical plexus travel in the sulcus between the anterior and posterior tubercles of the transverse process. They emerge from the spinal canal inferoposterior to the vertebral artery at the tip of the transverse process. It is

important to understand this relationship when using sonographic views to direct needle placement. In the transverse view, the nerve root emerges just posterior to the anterior tubercle, and in the longitudinal view, the nerve root travels obliquely within the sulcus posterior to the vertebral artery (Fig. 4).

Posterior triangle

From the carotid view, the probe is moved laterally from the paratracheal groove towards the posterior triangle. At the lateral edge of the sternocleidomastoid muscle, the probe is aligned in the axial oblique plane to lie transverse to the plexus. At this level, the plexus is covered by skin, platysma, and sternocleidomastoid muscle. At the base of the triangle, it is crossed by the inferior belly of the omohyoid muscle and the suprascapular and transverse cervical arteries (Fig. 2). Transverse examination of the plexus within the interscalene space defines the

Fig. 5 Transverse sonogram of the lower posterior triangle of the neck showing the interscalene view. *S* superior; *I* inferior; *A* anterior; *P* posterior

interscalene view with plexus roots and trunks (superior, middle, and inferior) discretely aligned as dark nodules sandwiched between anterior and middle scalene muscles.¹⁵ Superficially, the curved aponeurotic folds of these muscles typically form a recognizable dual-concave-shaped landmark (“*seagull sign*”) in most patients (Fig. 5). The external jugular vein and sternocleidomastoid muscle often overlie the interscalene space. In most cases, the phrenic nerve is visualized as a small monofascicular nerve originating from C₅ and travelling on the medial surface of anterior scalene.¹⁶

Interscalene brachial plexus block

The interscalene approach is commonly used in shoulder surgery where local anesthetic injection adjacent to the plexus trunks provides superior anesthesia to the shoulder joint. Injection may be in-plane anteriorly through the sternocleidomastoid muscle or posteriorly adjacent to or through the trapezius muscle. Alternatively, needle insertion can be performed out-of-plane, above the probe, and parallel to the interscalene groove. As local anesthetic is injected to surround the nerves, the space expands into a hypoechoic “*lens shape*” causing enhancement of nerve appearance. Simultaneous injection and advancement of the needle, or hydrodilatation, causes nerves to move away from the advancing needle-tip. An injectate volume of 30 mL will often spread cephalad to higher nerve root levels, over the anterior scalene to the phrenic nerve, medially to the sympathetic chain, and caudad to the

supraclavicular fossa. Larger volumes can also spread to the recurrent laryngeal nerve. Since nerves can be visually targeted and needles redirected during injection, much smaller injectate volumes may be used. Spread to the C₄ and C₃ levels can result in anesthesia of the supraclavicular nerves, which is advantageous for shoulder surgery. Alternatively, a superficial cervical plexus block may be performed at the posterior border of the sternocleidomastoid muscle at the level of C₃, a point which lies superior to the locus, inappropriately termed Erb’s point. (Wilhelm Erb transcutaneously elicited contractions of proximal arm muscles with electrical stimulation; the terms “Erb’s point” and “nerve point” have been mistakenly interchanged when describing the point of emergence of the cutaneous branches of the cervical plexus near the posterior border of the sternocleidomastoid muscle.¹⁷) Further it is important to observe the spread of injectate, since nerve roots may lie within muscle outside the interscalene space, or fibrous bands within the space may prevent spread.

The *high interscalene view* is seen when the probe is then moved cephalad from the interscalene view, and the nodular nerve roots may be traced back medially to the transverse process from where they originate between the anterior and posterior tubercles. The anterior scalene tapers into a pyridimal point at the level of the fifth or sixth cervical vertebra, and the C₅ nerve root lies in close proximity to, or within, the muscle adjacent to the transverse process of the vertebra. The carotid artery is seen to lie laterally (Fig. 6). Injection of local anesthetic at this level will spread towards the common carotid to the ansa

Fig. 6 Transverse sonogram of the mid posterior triangle showing the high interscalene view. *S* superior; *I* inferior; *A* anterior; *P* posterior

cervicalis and to the proximal cervical plexus roots. This can provide anesthesia of the anterior triangle of the neck, which is also suitable for carotid artery surgery.^{18,19} At this level of the posterior triangle, ultrasonography may allow visualization of the normal accessory nerve,²⁰ which traverses the triangle superficially and obliquely from the posterior junction of the upper and middle third of the sternocleidomastoid muscle to enter trapezius at the junction of its middle and clavicular third.

Supraclavicular space

Returning to the interscalene view, the probe is then directed downwards into the retroclavicular space and tilted to lie parallel with the first rib. As the plexus is followed downwards, the trunks are seen to divide into neural divisions and coalesce. Ultrasound identifies the divisions as a neural cluster (“grape-like”) in close proximity to the subclavian artery and the highly reflective first rib (Fig. 7). The pulsating artery acts as an identifiable landmark for the *supraclavicular view*, with the neural cluster typically positioned above and posterolateral to the artery. The nerves are usually discretely positioned and inferior to the omohyoid muscle. The cervical pleura lies in close proximity and medial to the artery.

Supraclavicular brachial plexus block

There is renewed interest with the supraclavicular approach in regional anaesthesia, since ultrasound guidance can successfully position needles and anesthetic spread with less risk of pneumothorax.²¹ The divisions of the plexus are tightly grouped at this level providing a high rate of success when injectate is placed here. Some may travel beneath the vessel adjacent to the rib and contribute to ulnar sparing if not blocked. Anterior or posterior approaches enable in-plane insertion and navigation of the needle. Careful note of the internal jugular vein and pleura should be made when anterior approaches are considered. The transverse cervical and suprascapular arteries, branches of the

subclavian artery, may be seen crossing the interscalene region. The dorsal scapular artery, if present, may be seen passing through the supraclavicular brachial plexus. Similarly, needle advancement should avoid these vessels as the needle-tip is directed through the fascial sheath also avoiding contact with the plexus divisions. A successful block is more likely by injecting local anesthetic in the corner between the nerves and the subclavian artery and the first rib.²²

Infraclavicular space

The *infraclavicular view* is obtained by placing the probe adjacent to the lower border of the clavicle at its midpoint. Adjustment to a lower frequency is required for deeper penetration through the pectoralis muscles. The many landmark approaches that exist for regional anesthesia of this region usually relate to the midpoint of the clavicle or to the palpable coracoid process. These landmarks define the two regions of the infraclavicular plexus, i.e., the proximal region where the plexus passes beneath the clavicle in the vicinity of the deltopectoral fascia, and the distal region where the plexus lies infero-medial to the coracoid process. In the proximal compartment, scanning identifies the pectoral muscles, axillary artery and vein, neural cords, and pleura (Fig. 8). The cephalic vein passes through the deltopectoral fascia to join the axillary vein. This venous junction is an identifiable sonographic landmark having an anechoic “*tadpole-shaped*” appearance.

As the plexus travels distally towards the coracoid process, the cords arrange themselves around the artery into medial, lateral, and posterior positions. The plexus can be mapped by advancing the probe across the chest in a parasagittal plane from beneath the mid-clavicle towards the axilla (Fig. 9). The pulsating axillary artery is positioned lateral to the compressible axillary vein. Superior to the vessels and plexus, the tendon of pectoralis minor can be traced laterally as it tapers and inserts into the highly reflective coracoid process with the appearance of a hyperechoic “*comet-tail*”.

Fig. 7 Transverse sonogram of the base of the posterior triangle showing the supraclavicular view. S superior; I inferior; A anterior; P posterior

Fig. 8 Transverse sonogram of the apex of the axilla showing the medial infraclavicular view. A anterior; P posterior; M medial; L lateral

Fig. 9 Transverse sonogram of the mid-axilla showing the lateral infraclavicular view. A anterior; P posterior; M medial; L lateral

Infraclavicular brachial plexus block

In-plane approaches are described for both proximal and distal regions. As the plexus enters the apex of the axilla nerve divisions and cords appear as cluster lateral to the artery, the plexus is more superficial and a proximal approach is claimed to provide better visualisation of the nerves, faster onset and less tourniquet pain.²³ However, in view of the axillary venous junction, this approach may be associated with a greater incidence of vascular puncture as well as proximity to the chest wall. The lateral or distal approach has needle entry adjacent to the coracoid process. Alternatively, a recently described²⁴ posterior approach may be employed where a needle enters from behind the lateral clavicle to reach the neurovascular bundle. Neural cords are arranged around the axillary artery, between 3 and 11 o'clock, and deep to muscle fascia²⁵ Irrespective of approach, successful block requires injectate to surround the artery and, in particular, to spread to the infero-medial quadrant.²⁶

Upper limb

With the arm abducted and supinated, the *axillary view* is obtained by moving the probe distally over the pectoral

fold to lie transversely across the bicipital groove. Examination identifies the axillary artery within this groove, which is formed by biceps and triceps muscles, multiple veins, and nerves (Fig. 10). The nerves are relatively superficial and, on transverse view, are usually arranged around the artery in a specific position or sector.²⁷ This arrangement can vary, but, in general, the median nerve is positioned between the biceps and the artery in the upper anterior axillary artery quadrant, the ulnar nerve in the opposite upper quadrant, and the radial nerve positioned posteriorly in the lower quadrants. The presence of multiple veins can alter this arrangement. Commonly, when the echogenic rims of the median and ulna nerves lie adjacent to the arterial rim, a recognizable pattern is formed. Branches of the terminal nerves vary in their origin, and multiple neural structures are often seen at the perivascular rim on scanning. The musculocutaneous nerve, recently described as a multifascicular nerve, changes shape from flat-oval to triangular as it travels laterally separate from the axillary artery within the body of the coracobrachialis muscle.²⁸ Similar mapping of terminal nerves distally will help identify each nerve, with the median nerve staying in close proximity to the artery as it travels down the arm, the ulnar nerve remaining more superficial, and the radial nerve travelling posteriorly towards the humerus. At the middle-third of the humerus, the radial nerve lies within the

Fig. 10 Transverse sonogram of the base of axilla for the axillary approach. A anterior; P posterior; M medial; L lateral

spiral groove where it is closely associated with the profunda brachii artery and vein. It then passes through the intermuscular septum to lie between the brachioradialis and brachialis muscles.²⁹

Axillary brachial plexus block

Complete axillary brachial plexus block requires targeting of the four terminal nerves. Perivascular deposition of local anesthetic around the axillary artery will often easily spread to the median, ulna, and radial nerves when they are not contained within fascial compartments. At the axilla, the plexus may be blocked via a single skin injection site (usually through biceps) with deposition of injectate at the musculocutaneous nerve, followed by needle re-direction and injection around the artery for perivascular spread.

The *distal brachial view* is achieved by placing the probe over the antecubital fossa, with the arm supinated and abducted. The median nerve is seen to lie medial and adjacent to the brachial artery, lateral to the medial epicondyle of the humerus. The lateral cutaneous nerve of the forearm runs superficially adjacent to (or over) the lateral edge of the biceps tendon and medial to the medial cubital vein. Above the lateral epicondyle, the radial nerve lies in the aponeurosis between the brachioradialis and brachialis muscles; it divides into the superficial radial and posterior interosseous nerves (Fig. 11). The median nerve can be mapped distally

as it travels down the arm between the flexor digitorum superficialis and flexor digitorum profundus. With the arm externally rotated and the probe placed over medial epicondyle, the ulnar nerve can be scanned posteriorly above the elbow in close relation to the triceps (and tendon). Below the elbow, it travels down the arm beneath flexor carpi ulnaris in association with the ulna artery.

At the *distal forearm*, the median nerve lies medial to flexor carpi radialis and lateral to or beneath palmaris longus as it travels to the wrist above flexor digitorum profundus (Fig. 12). At the wrist, the nerve then *tunnels* beneath the flexor retinaculum in association with tendons from flexor digitorum profundus and flexor digitorum profundus. This retinaculum forms a fascial plane between the pisiform and scaphoid bones. The ulnar nerve and artery lie medial and superior to the retinaculum within Guyon's canal adjacent to the pisiform. The ulnar artery forms the superficial palmar arch of the hand distal to the pisiform after sending out the deep palmar branch.

Anesthesia of peripheral nerves

Sonographic mapping identifies nerves as they travel down the arm, enabling them to be blocked distally.³⁰ This may be necessary for rescue analgesia in the advent of an incomplete brachial plexus block or for primary anesthesia of a surgical site. Dupuytren's surgery, involving the

Fig. 11 Transverse sonogram of the distal brachial region for the supracondylar approach. A anterior; P posterior; M medial; L lateral

Fig. 12 Transverse sonogram of the distal forearm for wrist block approach. A anterior; P posterior; M medial; L lateral

tendons of the fourth and fifth fingers, for example, can be performed successfully by injection of the ulna and median nerves in the mid to distal forearm under ultrasound guidance. Proximal injection enables easier identification of the ulnar nerve adjacent to the artery and the median nerve within the muscle fascia away from tendon structures. Such understanding of the innervation of a surgical site is essential for successful regional anesthesia.

Typical sonographic anatomy

The views described above depict typical sonographic landmarks, which indicate nerve location in relation to anatomical structure. The individual appearance of each component may vary, but the anatomical relationship of the pattern remains. This provides a platform for sonographic recognition. The interscalene space, for example, may appear compressed when the scalene muscles have flattened borders and are closely opposed. Despite the *seagull sign* being less discernable, the recognition of the muscles themselves and the fascial plane between them directs attention to the expected location of the nerve trunk position. Similarly, the nerve roots may appear as a cluster of nodules rather than three discrete trunks. A further strategy in interpreting sonoanatomy is to map nerves along their course, which enables the recognition of surrounding structures, thereby identifying anatomical relation. By mapping the interscalene space from the interscalene to the supraclavicular level, for example, nerve trunks will be seen to divide and arrange themselves adjacent to the readily identifiable subclavian artery, confirming the identification of the plexus. In addition, the C₅ nerve root is typically positioned at the apex of the anterior scalene muscle, a landmark which directs scanning to its position. The nerve root may sometimes be seen within the muscle itself or appear to have multiple components. Sonographic tracking of the C₅ root branch to the phrenic nerve aids in identifying the phrenic nerve as it travels inferiorly on the medial surface of the anterior scalene muscle. By understanding such anatomical relations, individual appearance can be correctly interpreted.

Anatomical variance

The human form commonly exhibits structural variation as well as asymmetry.³¹ In early embryonic development, primitive nerves form in the upper limb bud during the fourth week of gestation. Within the limb, bud sclerotome axonal growth occurs in close association with the development of the primitive capillary plexus and venous system. The developing brachial plexus acts as a neural network, which directs nerves with a common function into terminal nerves down the arm.

During development, variation in the neurovascular bundle can occur in both anatomical structure and position. By having an abnormal course or an aberrant or accessory origin, variant arteries can influence adjacent nerve position within the upper limb. Anatomical variation may occur in isolation or occur as a cluster of associated defects; for example, the presence of a retroesophageal subclavian artery (1% incidence) is associated with an altered right recurrent laryngeal nerve course (Fig. 13). In addition to normal variants, sonographic appearance may be altered by anatomical distortion arising from pathological processes, such as palsy,²⁰ infiltrating tumour, and trauma.³² Trauma can cause disruption of nerve continuity and cause focal scar formation. Primary and secondary tumours can appear as focal masses within a nerve or adjacent to it, or they can cause diffuse thickening of the nerve itself.³³ Therefore, there is a need for careful sonographic examination in all patients, together with an awareness that normal and pathological variation can occur. Nevertheless, the sonographer should be aware that anatomical variation, as discussed below, is not always evident in the key sonographic views. For example, aberrant, phrenic, or recurrent laryngeal nerves are unlikely to be visualized on ultrasound examination, but this context emphasizes that variation in both neural arrangement and anatomical relation can occur.

Anatomical variation in the neck

Anatomical variation relevant to the neck and upper limb anesthesia is shown in Table 2. The brachial plexus,

Fig. 13 Right subclavian artery arising from the distal aortic arch, travelling behind the esophagus to reach the right thoracic outlet; associated with an altered right recurrent laryngeal nerve course (not shown) (Reproduced with permission from Ref.⁴)

however, is an idealized representation, since anatomists have described marked variation in plexus configuration and symmetry. The anatomy of the brachial plexus in man has been extensively studied by Kerr,³⁴ who classified the neural arrangement of the plexus into seven subgroups. Dissection showed seven major configurations, each having <57% representation and asymmetry occurring in 60% (Table 3). The brachial plexus also commonly exhibits a variable degree of contribution from C₄ and T₂ nerve roots. A shift of plexus nerve roots can occur in up to 62%, where pre-fixed roots are derived from a more cranial position (C₄–C₈) or post-fixed when positioned more caudally (C₆–T₂). There may be associated vertebral column abnormalities, such as an increase in the number of vertebrae. Subsequent anatomical studies refer to this cadaveric work and further describe variations in the brachial plexus formation and main branches. The long thoracic nerve, for example, pierces the scalenus medius in 63%. The formation and origin of the plexus cords and median nerve is reported to vary in 12.8%.³⁵ In particular, there is variability in branching and location with respect to the axillary artery. Formation of the posterior cord by divisions of the superior and middle trunks without contributory C_{7–8}

Table 2 Examples of anatomical variants

<i>Neck</i>	
Neural	Pre- and post-fixation of spinal nerve roots Brachial plexus configuration of fibre pathways and asymmetry Phrenic nerve origin Nerves outside interscalene space Non-recurrent recurrent laryngeal nerve
Bony	Cranial shift of vertebral column Cervical rib with associated fibrous bands Elongated C ₇ transverse process
Vascular	Aortic arch branching (brachiocephalic, common carotid, subclavian) Left vertebral artery origin from aortic arch Right retroesophageal subclavian artery Subclavian artery branching at first rib Vertebral artery entry into C ₅ cervical transversarium
Muscular	Scalenus minimus Muscle slips associated with subclavian artery Long thoracic nerve piercing scalenus medius
<i>Upper limb</i>	
Neural	Brachial plexus variation in connection of fibre pathways (between neural cords, median, and musculocutaneous nerves) Musculocutaneous nerve course outside body of coracobrachialis
Bony	Supracondylar process with associated ligament of Struthers
Vascular	High division of axillary artery Aberrant branching of axillary artery High division of brachial artery Superficial ulnar artery Persistent median artery on median nerve Superficial palmar arch (complete and incomplete)
Muscular	Third head of biceps brachii Absent palmaris longus

fibres to the axillary and radial nerves has a 9% incidence.³⁶ The posterior cord may be absent in 3.5%, and the median nerve roots may fail to join and travel separately anteromedial to the axillary and brachial arteries. Variation in the formation and branching of brachial plexus nerve fibres will directly impact on the clinical assessment of upper limb innervations, and aberrant or absent nerves will impact on their ability to be localized on ultrasound examination.

Variations in the phrenic nerve include it arising from cervical roots lower than C₄ or receiving contributions from cranial nerves XI and XII. With pre-fixation, the phrenic nerve can have its complete origin from the brachial plexus occurring in up to 20% of cases.³⁶ An accessory phrenic nerve may arise from the nerve to the

Table 3 Brachial plexus patterns observed from cadaveric study (adapted from Ref.³⁵)

Group	Spinal root	Type	Trunk	Fascicle (cord)	%
I	C ₄	A		C ₇ to medial cord	3
		B		No C ₇ to medial cord	57
		C	Cephalic	C ₈ to lateral cord	2
II	C ₅ /No C ₄	D	Intermediate	Intermediate trunk to medial cord	0.5
		E	Caudal	No C ₇ to medial cord	30
III	Part of C ₅	F		C ₅ to cervical plexus	7
		G		Caudal trunk to lateral cord	<0.5

Fig. 14 Bilateral cervical ribs arising from C₇ vertebra. This may be partial or complete and is commonly associated with fibrous band (Reproduced with permission from Ref.⁴)

subclavius muscle and travel anterior to the subclavian vein rather than posterior to it. Such variation can have clinical consequences when inadvertent anesthesia of the phrenic nerve results in hemidiaphragmatic paresis and reduction in forced vital capacity.³⁷ The recurrent laryngeal nerve, which arises from the vagus nerve, is non-recurrent on the right (1:200). The middle supraclavicular nerve can directly pierce the clavicle rather than travel superficially to it, and the thoracic duct may be present on the right.

The presence of a cervical rib (Fig. 14) or abnormal fibrous band can lead to the thoracic outlet syndrome (TOS) where compression of the neurovascular bundle presents clinically as Raynauds syndrome, vascular insufficiency, or a neurological deficit including pain.³⁸ When the arms are elevated, symptoms are exacerbated by vessel compression, which decreases radial artery flow as detected using Doppler flowmetry. On leaving the neck, the subclavian vessels and brachial plexus travel through three compartments where compression can occur: the interscalene triangle, the costoclavicular space, and the retropectoralis

minor space.³⁹ Anatomic abnormalities, either skeletal or soft tissue, as well as acquired disease can cause the syndrome.

Cervical ribs, present in 1% of the normal population, occur in 5–9% of patients with TOS, and are commonly associated with fibrous bands.⁴⁰ A cervical rib arising from the C₇ transverse process can be unilateral, bilateral, or partial and is associated with other anomalies, such as a cranial shift of the plexus and a short twelfth rib. Complete cervical ribs can fuse with the first rib adjacent to the scalenus anterior muscle and displace the subclavian artery anteriorly. Fibrous bands can similarly insert onto the rib compressing neural structures. If a cervical rib is present, the subclavian artery may run above this rib. Other skeletal abnormalities include an elongated C₇ transverse process and abnormal first rib orientation, as well as bony exostosis, callus, and tumour. Such variations will alter the typical sonographic appearance of the interscalene and supraclavicular views.

In the embryo, the aortic arch develops from the branchial arches to typically form three branches in 80% of people, i.e., the right brachiocephalic trunk, the left common carotid artery, and the left subclavian artery. In 11%, a common stem exists for the brachiocephalic trunk and the left common carotid artery, with the left subclavian artery arising independently from the arch.³¹ When five arteries develop, extra branches are usually the right subclavian and the left vertebral. With the presence of a left vertebral artery, the variation of four vessels has a frequency of about 5%. Less common vascular variations include the development of an avian aortic arch with two branches, a double aorta, or an inverted right-sided aorta (<0.5%). In addition, the right common carotid artery may obliquely cross the lower part of the trachea above the level of the sternum and appear absent on examination. This occurs particularly on the right side when the right brachiocephalic trunk is situated to the left of the midline, or when the right and left common carotid arteries arise as a common stem from the aorta. Common carotid bifurcation may be high, up to the level of the styloid process, or low, below the cricoid cartilage. The common carotid artery itself may be absent, with external and internal carotids arising directly from the arch of the aorta.

Vascular variants at the thoracic outlet include the subclavian artery either perforating the scalenus anterior muscle with associated muscle slips or passing anterior to the muscle. The subclavian vein occasionally accompanies the artery behind the scalenus anterior muscle. The artery may also travel between scalenus medius and posterior. When the right subclavian artery is the last branch of the aortic arch, it may be retroesophageal (Fig. 13), travelling behind the esophagus to reach the right side (0.5%). As a consequence, the recurrent laryngeal nerve follows a direct course to the larynx instead of winding recurrently around the subclavian artery. Alternatively, the artery may also pass between the esophagus and the trachea causing compression of the esophagus (*dysphagia lusoria*), or it may pass in front of the trachea itself. The artery can ascend above or remain below the level of the clavicle. On the right, the thoracic duct may drain into the artery, and on the left, the artery may receive a patent ductus arteriosus. The subclavian and axillary arteries also exhibit variation in their branching, with the thyrocervical trunk and the vertebral artery having a variable origin and course. The vertebral artery may take an abnormal course, rather than its normal course to the sixth cervical vertebra, and enter the transversarium of the fifth cervical vertebra (5%) or, less commonly, the seventh, fourth, or third. In some cases, the subclavian artery divides at the medial border of the scalenus anterior muscle, with the two branches continuing through the axilla and down the arm to become the radial and ulnar arteries.

The paravertebral scalene muscles commonly exhibit variation in muscle formation, insertion site, and relation to the brachial plexus. A recent prospective ultrasound study of the scalene triangle indicated the incidence of anatomical variation to be 13%.⁴¹ Nerve roots and trunks can lie outside the interscalene space,⁴² or they can pierce the scalene muscle belly as they travel towards the rib. Their course may also be altered by the presence of a scalenus minimus muscle, which commonly⁶ appears on ultrasound as a triangular slip of muscle between the scalenus anterior and medius (Fig. 15). It arises from the anterior tubercle of the C₆₋₇ transverse process and attaches to the first rib

behind the subclavian groove. It can spread over the cupola of the lung, providing an extra fascial layer over the suprapleural membrane (Sibson's fascia). Variation in scalene muscle formation also includes hypertrophied anterior or middle scalene muscles and middle and anterior scalenes sharing a common muscle belly.⁴⁰ Such variations can result in segments of the plexus being contained within separate fascial compartments, thereby preventing contact with injectate and leading to a failure of anesthesia.

Anatomical variation in the upper limb

Early anatomists have shown the axillary artery to exhibit variation in its origin, course, and branching^{43,44} and case reports are multiple. The classic branching pattern of the axillary artery may be as low as 10%. Occasionally a high proximal division gives rise to the radial artery or, more rarely, the ulnar or interosseous arteries. An aberrant posterior circumflex humeral artery can arise from the subscapular artery (20%) instead of from the axillary artery, and an aberrant profunda brachii can arise from the posterior circumflex humeral artery (7%) instead of from the brachial artery. These vessels may also arise from a common trunk of the axillary artery. The brachial plexus tends to follow these aberrant vessels rather than the original axillary artery. Variant artery formation can therefore influence nerve position within the neurovascular bundle.

The musculocutaneous nerve typically arises from the lateral cord, though it may also arise from the posterior (4%) or medial (2%) cord. There are also frequent connections between the musculocutaneous and median nerves, as well as multiple interconnections between the plexus cords and branches being described. The point of entry of the musculocutaneous nerve into the coracobrachialis muscle is variable, as is the branching of the motor nerves to the flexor muscles. The coracobrachialis is a tricipital muscle in some animals, and in humans the lower head is suppressed with the upper two heads fusing together and encasing the musculocutaneous nerve between them. The persistence of a lower head, however, can be associated with the presence of a supracondylar process

Fig. 15 Transverse sonogram of the base of the posterior triangle showing an atypical supraclavicular view with the presence of a scalenus minimus muscle, leading to separate fascial compartments of the brachial plexus. A anterior; P posterior; M medial; L lateral

Fig. 16 Supracondylar spur of the humerus associated with a fibrous band (Ligament of Struthers) (Reproduced with permission from Ref.⁴)

(spur) and a fibrous band (Ligament of Struthers), which attaches to the medial epicondyle of the humerus (Fig. 16). Associated entrapment of the median nerve occurs in 0.8%. Although the musculocutaneous nerve passes within the body of the coracobrachialis muscle in most arms, it may travel in close or partial association with the median nerve in as many as 8–30% of arms.^{45,46}

The musculocutaneous nerve may also contribute a more extensive sensory supply to the hand than is described by anatomic texts.⁴⁷ The hand is divided into discrete sensory dermatomes, with sensation of the thumb being divided into volar innervation by the median nerve and dorsal innervation by the superficial radial nerve. The lateral cutaneous nerve of the forearm arising from the musculocutaneous nerve can extend distally to innervate the dorsal surface of the thumb and hand. This has relevance when surgery is performed on the base of the thumb.

A high proximal division of the brachial artery, usually in the upper third of the arm or more proximally in the axillary artery, occurs in 4–6%. Terminal branches of the radial, ulnar, common interosseous, or superficial median antebrachial artery are formed. The vessels usually run parallel to supply the forearm in the usual position, though variations in their size and arrangement can occur.³¹ The main supply of the hand in the embryo is the median artery, which may persist in the adult (8%). This small vessel originates usually from the interosseous artery and is seen as a small vessel travelling down the forearm adjacent to

the median nerve. An ulnar artery arising from a high bifurcation (3%) travels superficially and medially down the forearm crossing the median nerve and the brachial artery to form the superficial ulnar artery. The radial artery arises from a high bifurcation more frequently (12%), but variation within the forearm is less than with the ulnar artery. The vessel may have a tortuous course, may be hypoplastic or form loops. At the anatomical snuff box, the artery may cross the extensor tendons of the thumb to form the arteria radialis superficialis. The absence of the palmaris longus tendon and associated tendons is common (15%). The ulnar artery is considered by most to be the dominant vessel at the wrist, based on having a slightly larger diameter and increased flow profile. However, the picture is not clear-cut, since variability in size and partial flow dominance to all or some of the digits is frequent. The superficial palmar arch is subject to significant variation, particularly on the radial side, with a complete arch linked to the superficial palmar branch of the radial artery occurring in <30%.

Conclusion

Ultrasound guided anesthesia has given new life to the appreciation of clinical anatomy. The pattern recognition of normal sonographic landmarks is an important strategy in anatomical orientation and identification of nerves. Anatomical variation, as well as pathological distortion of anatomy, can provide a challenge to the examiner when interpreting the appearance of a sonogram. Therefore, correct interpretation of a sonogram requires a careful and complete sonographic examination of the anatomical area using strategies such as neural mapping to define anatomical relation. In addition, recent discussion has been voiced concerning the management of unexpected findings during ultrasound-guided blocks.⁴⁸ There is a view that when performing an ultrasound-guided nerve block, the anesthesiologist should also perform a *pre-procedure scan* of the perineural region for pathology and appropriately interpret any abnormal appearance.⁴⁹ This calls the ability to distinguish normal from abnormal further into question, as well as whether sufficient expertise for appropriate diagnosis and management exists. Training and credentialing in ultrasound-guided techniques not only requires a sound knowledge of anatomy, but also now appears to be encompassing the field of diagnostics. Nevertheless, knowledge of anatomical detail and an awareness that anatomical variation may occur will enable atypical appearances to be correctly identified. Performing ultrasound guidance in this manner should contribute to accurate and safe needle placement, resulting in successful brachial plexus blockade.

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References

- Awad IT, Chan V. Ultrasound imaging of peripheral nerves: a need for a new trend. *Reg Anesth Pain Med* 2005; 30: 321–3.
- Marhofer P, Chan VW. Ultrasound-guided regional anesthesia: current concepts and future trends. *Anesth Analg* 2007; 104: 1265–9.
- Azer SA, Eizenberg N. Do we need dissection in an integrated problem-based learning medical course? Perceptions of first- and second-year students. *Surg Radiol Anat* 2007; 29: 173–80.
- Eizenberg N, Briggs C, Adams C, Ahern G. *Anatomesia; General Anatomy: Principles and Applications*. 1st ed. McGraw-Hill; 2008. ISBN 9780070134676
- Tsui BC, Dillane D, Pillay J, Ramji AK, Walji AH. Cadaveric ultrasound imaging for training in ultrasound-guided peripheral nerve blocks: lower extremity. *Can J Anesth* 2007; 54: 475–80.
- Harry WG, Bennett JD, Guha SC. Scalene muscles and the brachial plexus: anatomical variations and their clinical significance. *Clin Anat* 1997; 10: 250–2.
- Royse CE, Sha S, Soeding PF, Royse AG. Anatomical study of the brachial plexus using surface ultrasound. *Anaesth Intensive Care* 2006; 34: 203–10.
- Sites BD, Brull R, Chan VW, et al. Artifacts and pitfall errors associated with ultrasound-guided regional anesthesia. Part I: understanding the basic principles of ultrasound physics and machine operations. *Reg Anesth Pain Med* 2007; 32: 412–8.
- Sites BD, Brull R, Chan VW, et al. Artifacts and pitfall errors associated with ultrasound-guided regional anesthesia. Part II: a pictorial approach to understanding and avoidance. *Reg Anesth Pain Med* 2007; 32: 419–33.
- Shanewise JS, Cheung AT, Aronson S, et al. ASE/SCA guidelines for performing a comprehensive intraoperative multiplane transesophageal echocardiography examination: recommendations of the American Society of Echocardiography Council for Intraoperative Echocardiography and the Society of Cardiovascular Anesthesiologists Task Force for Certification in Perioperative Transesophageal Echocardiography. *Anesth Analg* 1999; 89: 870–84.
- Sandeman DJ, Griffiths MJ, Lennox AF. Ultrasound guided deep cervical plexus block. *Anaesth Intensive Care* 2006; 34: 240–4.
- Martinoli C, Bianchi S, Santacrose E, Pugliese F, Graif M, Derchi LE. Brachial plexus sonography: a technique for assessing the root level. *AJR Am J Roentgenol* 2002; 179: 699–702.
- Shibata Y, Fujiwara Y, Komatsu T. A new approach of ultrasound-guided stellate ganglion block. *Anesth Analg* 2007; 105: 550–1.
- Janik JE, Hoeft MA, Ajar AH, Alsofrom GF, Borrello MT, Rathmell JP. Variable osteology of the sixth cervical vertebra in relation to stellate ganglion block. *Reg Anesth Pain Med* 2008; 33: 102–8.
- Chan VW. Applying ultrasound imaging to interscalene brachial plexus block. *Reg Anesth Pain Med* 2003; 28: 340–3.
- Kessler J, Schafhalter-Zoppoth I, Gray AT. An ultrasound study of the phrenic nerve in the posterior cervical triangle: implications for the interscalene brachial plexus block. *Reg Anesth Pain Med* 2008; 33: 545–50.
- Tubbs RS, Loukas M, Salter EG, Oakes WJ. Wilhelm Erb and Erb's point. *Clin Anat* 2007; 20: 486–8.
- Merle JC, Mazoit JX, Desgranges P, et al. A comparison of two techniques for cervical plexus blockade: evaluation of efficacy and systemic toxicity. *Anesth Analg* 1999; 89: 1366–70.
- Roessel T, Wiessner D, Heller AR, Zimmermann T, Koch T, Litz RJ. High-resolution ultrasound-guided high interscalene plexus block for carotid endarterectomy. *Reg Anesth Pain Med* 2007; 32: 247–53.
- Bodner G, Harpf C, Gardetto A, et al. Ultrasonography of the accessory nerve: normal and pathologic findings in cadavers and patients with iatrogenic accessory nerve palsy. *J Ultrasound Med* 2002; 21: 1159–63.
- Chan VW, Perlas A, Rawson R, Odukoya O. Ultrasound-guided supraclavicular brachial plexus block. *Anesth Analg* 2003; 97: 1514–7.
- Soares LG, Brull R, Lai J, Chan VW. Eight ball, corner pocket: the optimal needle position for ultrasound-guided supraclavicular block. *Reg Anesth Pain Med* 2007; 32: 94–5.
- Bigeleisen P, Wilson M. A comparison of two techniques for ultrasound guided infraclavicular block. *Br J Anaesth* 2006; 96: 502–7.
- Hebbard P, Royse C. Ultrasound guided posterior approach to the infraclavicular brachial plexus. *Anaesthesia* 2007; 62: 539.
- Sauter AR, Smith HJ, Stubhaug A, Dodgson MS, Klaastad O. Use of magnetic resonance imaging to define the anatomical location closest to all three cords of the infraclavicular brachial plexus. *Anesth Analg* 2006; 103: 1574–6.
- Bloc S, Garnier T, Komly B, et al. Spread of injectate associated with radial or median nerve-type motor response during infraclavicular brachial-plexus block: an ultrasound evaluation. *Reg Anesth Pain Med* 2007; 32: 130–5.
- Retzl G, Kapral S, Greher M, Mauritz W. Ultrasonographic findings of the axillary part of the brachial plexus. *Anesth Analg* 2001; 92: 1271–5.
- Schafhalter-Zoppoth I, Gray AT. The musculocutaneous nerve: ultrasound appearance for peripheral nerve block. *Reg Anesth Pain Med* 2005; 30: 385–90.
- Foxall GL, Skinner D, Hardman JG, Bedforth NM. Ultrasound anatomy of the radial nerve in the distal upper arm. *Reg Anesth Pain Med* 2007; 32: 217–20.
- McCartney CJ, Xu D, Constantinescu C, Abbas S, Chan VW. Ultrasound examination of peripheral nerves in the forearm. *Reg Anesth Pain Med* 2007; 32: 434–9.
- Bergman RA, Thomson SA, Afifi AK, Saadeh FA. *Compendium of Human Anatomic Variation*. Munich: Urban and Schwarzenberg; 1998.
- Bodner G, Buchberger W, Schocke M, et al. Radial nerve palsy associated with humeral shaft fracture: evaluation with US—initial experience. *Radiology* 2001; 219: 811–6.
- Graif M, Martinoli C, Rockkind S, et al. Sonographic evaluation of brachial plexus pathology. *Eur Radiol* 2004; 14: 193–200.
- Kerr A. The brachial plexus of nerves in man, the variations in its formation and branches. *Am J Anat* 1918; 23: 285–395.
- Pandey SK, Shukla VK. Anatomical variations of the cords of brachial plexus and the median nerve. *Clin Anat* 2007; 20: 150–6.
- Fazan V, Amadeu A, Caleffi A, Filho C. Brachial plexus variations in its formation and main branches. *Acta Cir Bras* 2003; 18: 14–8.
- Bigeleisen PE. Anatomical variations of the phrenic nerve and its clinical implication for supraclavicular block. *Br J Anaesth* 2003; 91: 916–7.

38. *Cooke RA*. Thoracic outlet syndrome—aspects of diagnosis in the differential diagnosis of hand-arm vibration syndrome. *Occup Med (Lond)* 2003; 53: 331–6.
39. *Ranney D*. Thoracic outlet: an anatomical redefinition that makes clinical sense. *Clin Anat* 1996; 9: 50–2.
40. *Roos DB*. Congenital anomalies associated with thoracic outlet syndrome, Anatomy, symptoms, diagnosis, and treatment. *Am J Surg* 1976; 132: 771–8.
41. *Kessler J, Gray AT*. Sonography of scalene muscle anomalies for brachial plexus block. *Reg Anesth Pain Med* 2007; 32: 172–3.
42. *Chin KJ, Niazi A, Chan V*. Anomalous brachial plexus anatomy in the supraclavicular region detected by ultrasound. *Anesth Analg* 2008; 107: 729–31.
43. *Hitzrot J*. A Composite Study of the Axillary Artery in Man. London: John Hopkins Hosp Bull; 1901. p. 136–45.
44. *Poynter C*. Congenital anomalies of the arteries and veins of the human body with bibliography. *Univ Stud Univ Nebr* 1920; 22: 1–106.
45. *Flatow EL, Bigliani LU, April EW*. An anatomic study of the musculocutaneous nerve and its relationship to the coracoid process. *Clin Orthop Relat Res* 1989; 244: 166–71.
46. *Eglseder WA Jr, Goldman M*. Anatomic variations of the musculocutaneous nerve in the arm. *Am J Orthop* 1997; 26: 777–80.
47. *Falconer D, Spinner M*. Anatomic variations in the motor and sensory supply of the thumb. *Clin Orthop Relat Res* 1985; 195: 83–96.
48. *Sites BD, Spence BC, Gallagher JD, Beach ML*. On the edge of the ultrasound screen: regional anesthesiologists diagnosing nonneural pathology. *Reg Anesth Pain Med* 2006; 31: 555–62.
49. *Manickam BP, Perlas A, Chan VW, Brull R*. The role of a preprocedure systematic sonographic survey in ultrasound-guided regional anesthesia. *Reg Anesth Pain Med* 2008; 33: 566–70.