5 Brachial Plexus Blocks

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Contents

Anatomy

The brachial plexus (BP) is entirely responsible for innervation of the upper limb (Figs. 5.1, 5.2, 5.3, and 5.4). It has the shape of an hourglass whose middle part, narrowed, is crossed by the clavicle which determines a supraclavicular, cervical part and an infraclavicular, axillary part [1] (Figs. 5.5, 5.6, 5.7, 5.8, and 5.9). It is formed at its origin by the ventral branches of the cervical nerve roots of C5 to C8 and of the thoracic nerve root T1 (an anastomosis of C4 and/or T2 can occur). When passing between the anterior and middle scalene muscles, these branches develop interconnections and form three trunks:

– *The upper trunk*, formed by the union of ventral branches C5 and C6.
– *The middle trunk*, comprised of the ventral branch C7.
– *The inferior trunk,* formed by union of the ventral branches C8 and T1. Behind and above the clavicle, each trunk divides into two branches (one anterior and the other posterior) which give rise to the following cords:
– *The posterior cord,* resulting from the union of the three dorsal branches.
– *The lateral cord*, resulting from the union of the ventral branches of the upper and middle trunks.
– *The medial cord* comprised of the ventral branch of the inferior trunk.

Several variations of this configuration of interconnections exist, in particular, as the result of the variable distributions between the ventral branch of the middle trunk (C7)

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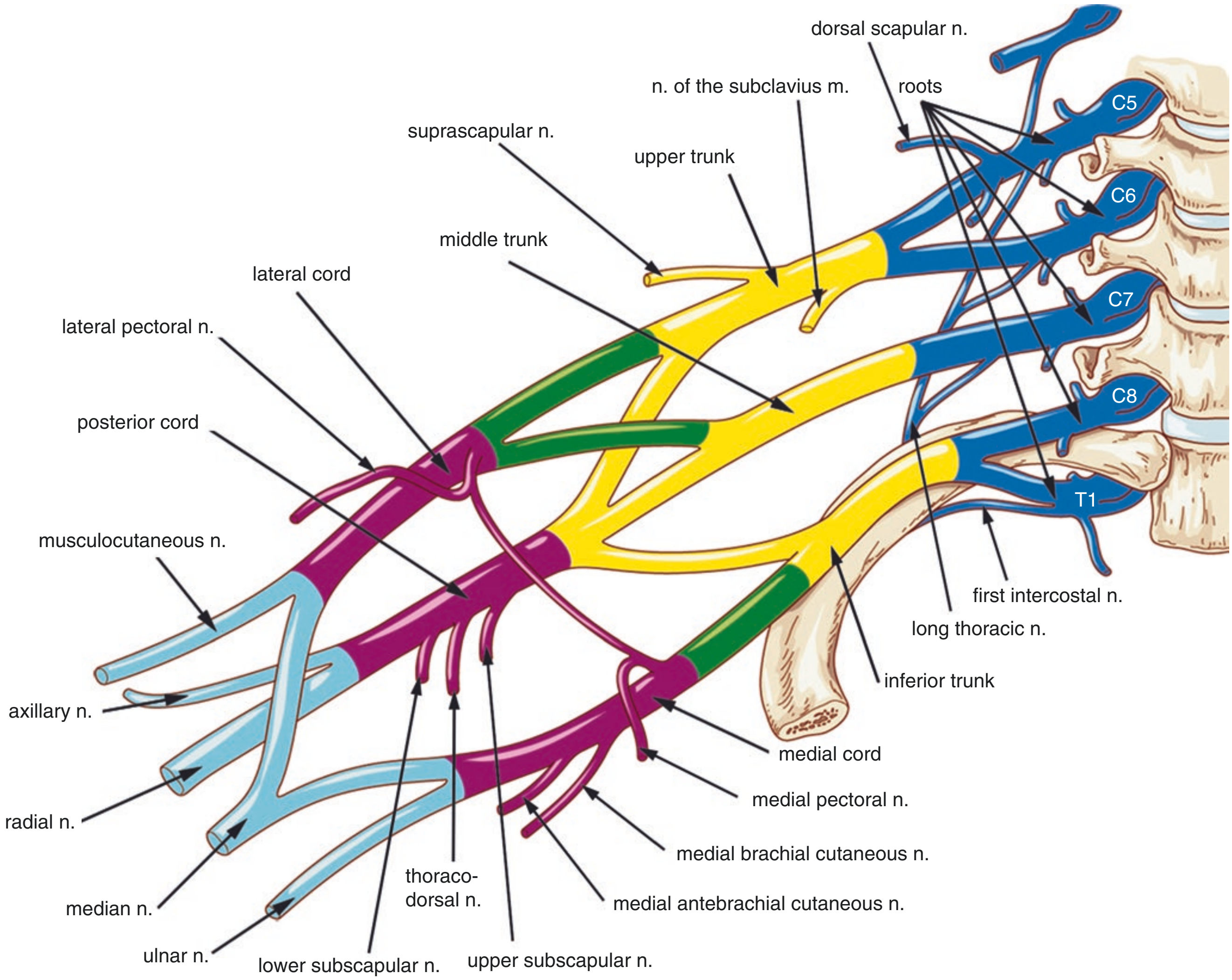


Fig. 5.1 Schematic diagram of brachial plexus

and the lateral or medial cord [2]. These variations have minimal clinical implications relating to the ulnar nerves (C8-T1) and axillary nerve (C5-C6), although they may affect the nerve root origin of some nerve fibres contained in the terminal branches of the brachial plexus [3]. For example, the musculocutaneous nerve (usually C5-C6) may contain fibres from the nerve root of C7. The brachial plexus gives rise to terminal branches in the lateral border of the pectoralis minor muscle:

- The posterior cord gives rise to the axillary (C5-C6) and radial (C5-T1) nerves.
- The lateral cord gives rise to the musculocutaneous nerves (C5-C6-C7) and the lateral root of the medial nerve (C5-C6-C7).
- The medial cord gives rise to the medial root of the median nerve (C6-C7), as well as the ulnar nerve (C8-T1), the medial cutaneous nerve in the arm and the medial cutaneous nerve in the forearm.

Among the Collateral Branches

The Dorsal Scapular Nerve

The dorsal scapular nerve is a collateral branch of the brachial plexus, usually arising from the C5 root, just before the upper trunk formation; a small quota of fibre of C3 and C4 roots may associate with it. It is a motor nerve emerging at the supraclavicular part of the plexus. Once the dorsal scapular nerve pierces the middle scalene muscle, it continues downwards and backwards, deep to levator scapulae then rhomboid muscles. It provides motor innervation to the levator scapulae muscle and the minor and major rhomboid muscles. The nerve is accompanied by either the dorsal scapular

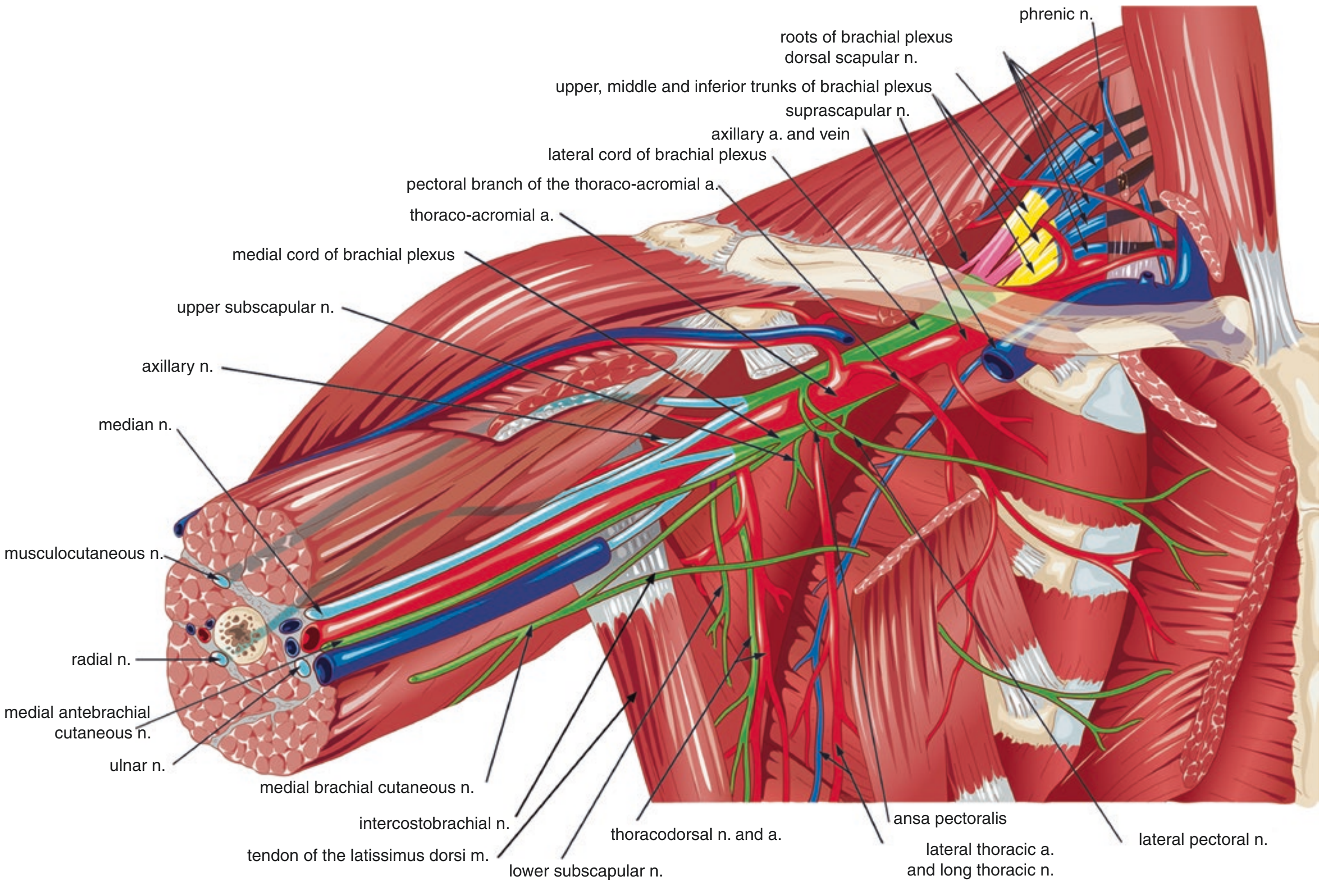


Fig. 5.2 Brachial plexus. (From Netter FH. *Atlas of human anatomy*. 3rd ed. Paris: Masson, 2007)

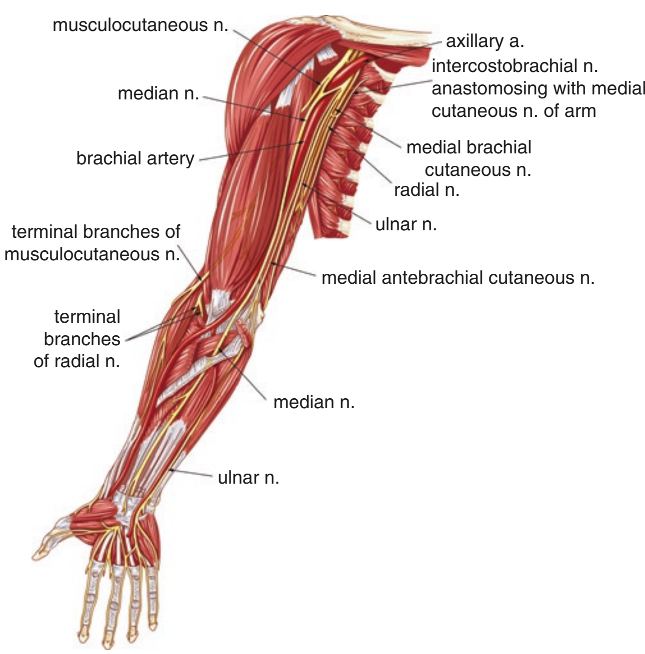


Fig. 5.3 Ventral aspect of upper limb. Terminal branches of brachial plexus

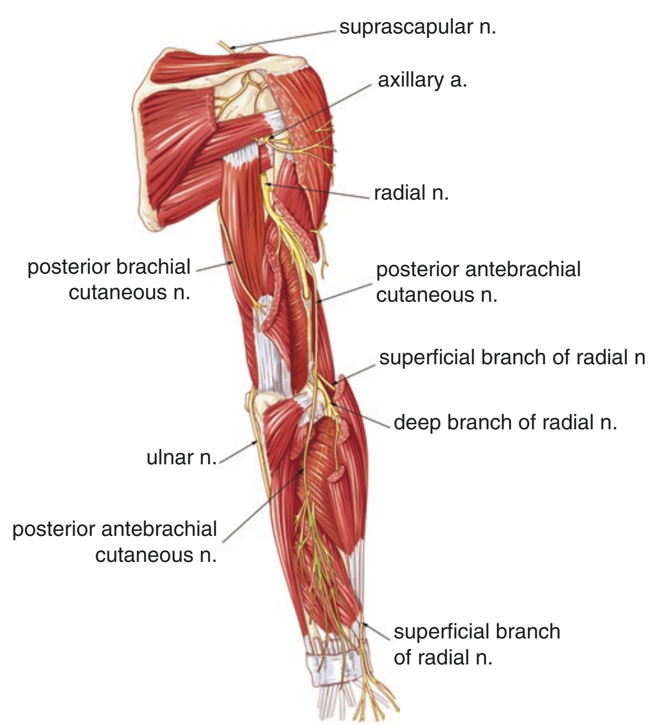
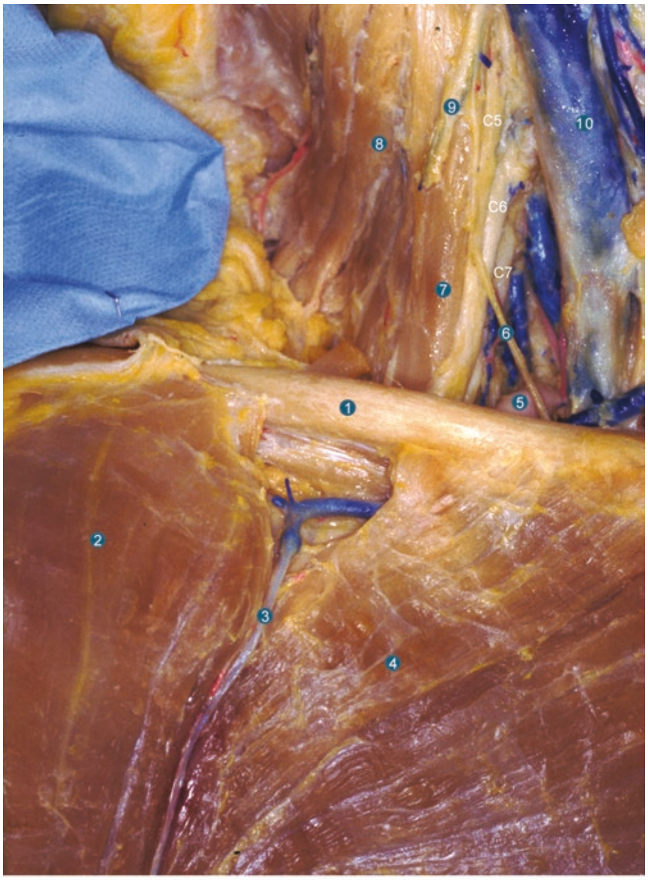
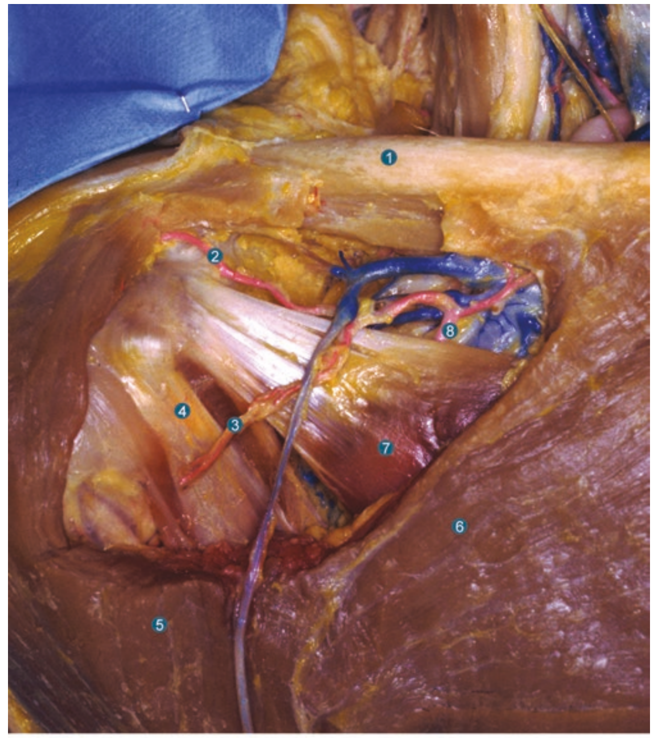


Fig. 5.4 Dorsal aspect of upper limb. Terminal branches of brachial plexus



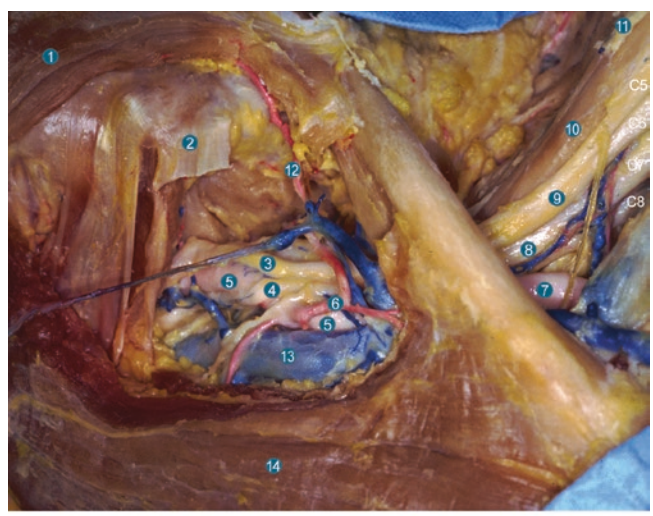
1. clavicle 2. deltoid m. 3. cephalic vein 4. pectoralis major m.
6. phrenic n. (anterior scalene m. removed) 7. middle scalene m.
8. levator scapular m. 9. suprascapular n.

Fig. 5.5 Cervical, supra- and infraclavicular areas: superficial view. (Dissection: Bertrand Fabre)



1. clavicle 2. acromial branch of the thoracoacromial a.
3. deltoid branch of the thoracoacromial a.
4. coracobrachialis m. 5. deltoid m. 6. pectoralis major m.
7. pectoralis minor m. 8. thoracoacromial a.

Fig. 5.6 Cervical, supra- and infraclavicular areas: resection of a portion of the pectoralis major muscle. (Dissection: Bertrand Fabre)



1. Deltoid m. 2. tendon of the pectoralis minor m.
3. lateral cord 4. medial cord
5. axillary a. 6. thoracoacromial a.
7. subclavian a. 8. middle trunk
9. upper trunk 10. middle scalene m.
11. suprascapular n. (removed)
12. acromial branch of the thoracoacromial a.
13. axillary v. 14. pectoralis major m.

Fig. 5.7 Cervical, supra- and infraclavicular areas: brachial plexus, principal vascular structures, relations with the clavicle. (Dissection: Bertrand Fabre)

artery (branching off the third part of the subclavian artery), or the deep branch of the cervical transverse artery (branching off the thyrocervical trunk) when the dorsal scapular artery is absent.

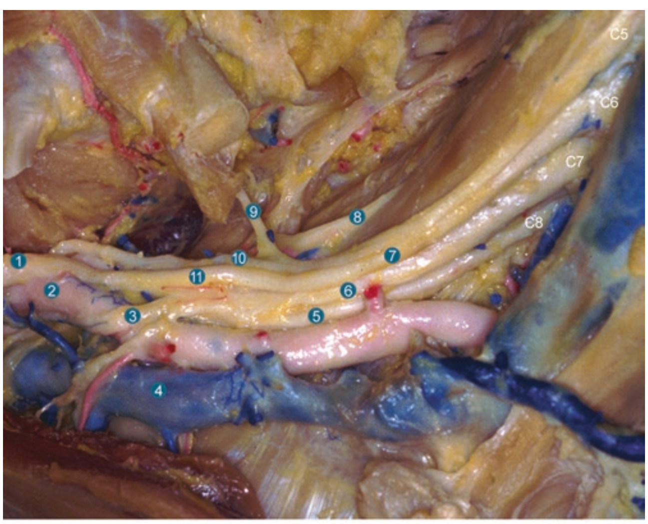
The Long Thoracic Nerve

The long thoracic nerve, also called the “Charles Bell nerve”, is a nerve that is essentially a motor nerve, responsible exclusively for innervation of the serratus anterior muscle. It arises from the anterior branches of roots of C5 and C6, of C7 in over two-thirds of cases, and of C4 and C8 very rarely. It is described as having two portions:

- **Cervical pathway:** Branches from C5 to C6 most often pass through the middle scalene muscle, and then joins with the branch that arises from C7 which passes between the middle scalene muscle and the anterior scalene muscle, behind the vascular bundle. The nerve then leaves the remainder of the axillary neurovascular bundle opposite

1. lateral cord
2. axillary a.
3. medial cord
4. axillary v.
5. cephalic v.
6. n. to subclavius m.
7. clavicle (removed)
8. anterior division of upper trunk
9. dorsal scapular n.
10. middle scalene m.
11. suprascapular n. (removed)
12. upper trunk
13. middle trunk
14. inferior trunk
15. subclavian a.

Fig. 5.8 Cervical, supra- and infraclavicular areas: brachial plexus, principal vascular structures, resection of the clavicle. (Dissection: Bertrand Fabre)



1. lateral cord
2. axillary a.
3. medial cord
4. axillary v.
5. inferior trunk
6. middle trunk
7. upper trunk
8. dorsal scapular n.
9. n. to subclavius m.
10. posterior division of upper trunk
11. anterior division of upper trunk

Fig. 5.9 Brachial plexus in the interscalene and supraclavicular area. (Dissection: Bertrand Fabre)

the second rib. Between its exit from the scalene muscle and the posterior angle of the second rib, it then descends obliquely from front to back creating an angle of about 30° with the horizontal plane in the sheath of the brachial plexus. By reflecting on the second rib, the nerve then entirely changes direction and becomes vertical.

- **Thoracic trajectory:** The thoracic part of the trajectory of the long thoracic nerve is relatively constant. It emerges from the axillary fossa under the pectoral muscles, opposite the fourth or fifth digitation. In the projection, the long thoracic nerve is always behind the midaxillary line, that is, posterior to the cutaneous branches which emerge from the intercostal bundle. In the distal part of its trajectory, it is joined by the branch of the anterior division of the thoracodorsal artery. This artery passes in front of the nerve at the point that it penetrates under the fascia of the serratus anterior muscle. The nerve divides into three terminal branches in 96% of cases for the middle and lower segments of the serratus anterior muscle. This division lies between 3 and 5 cm in front of the apex of the scapula.

The length of the nerve, after the union of the proximal branches, varies from 24 to 30 cm. The diameter of the nerve varies from 2.2 to 1.4 mm between its proximal portion and its ending.

Pectoral Nerves Loop (Ansa Pectoralis), Medial and Lateral Pectoral Nerves

The loop of the pectoral nerves is an anterior collateral branch of the brachial plexus resulting from branches from the lateral and medial cords: the lateral pectoral arises from the lateral cord, and the medial pectoral nerve arises from the medial cord. The ansa pectoralis finds its origin in the roots C5, C6, C7, C8 and T1. It is located close to the thoracoacromial artery, after the departure of the branch which goes to the latissimus dorsi muscle.

The pectoralis major muscle is innervated by the lateral pectoral nerve and the medial pectoral nerve resulting from the loop of the pectoral nerves (branches resulting from the C5-C6-C7). Each muscle head (clavicular, sternal and abdominal) has its own neurovascular pedicle.

The pectoralis minor muscle is innervated by a single branch of the pectoral loop (branches resulting from the C7-C8-T1 nerves).

Thoracodorsal Nerve

The thoracodorsal nerve arises from the posterior bundle of the brachial plexus (from C6-C7-C8 roots). The posterior bundle gives rise to the thoracodorsal nerve, the subscapular nerves, the axillary nerve and lastly the radial nerve. The thoracodorsal nerve emerges just downstream from the emergence of the axillary nerve.

This nerve passes inferiorly along the posterior wall of the axillary fossa and penetrates the medial aspect of the latissimus dorsi, where it becomes tendinous. It also innervates the teres major muscle. The end part of the nerve lies in front of the scapular lymphatic chain and the subscapular artery.

Terminal Branches of the Brachial Plexus

Axillary Nerve

The axillary nerve is a mixed nerve. Its roots of origin are C5 and C6; its fibres then follow the upper trunk and then the posterior cord. It passes behind the axillary artery and joins the interior border of the subscapular muscle. It passes under the capsule of the scapulohumeral joint and through the quadrangular space. It connects dorsally to the surgical head of the humerus. It gives rise to branches for the subscapular muscle, the ventral and dorsal aspects of the capsule, the teres minor muscle, the long head of the triceps brachialis muscle, one branch for each of the deltoid muscle, and it innervates the skin in the upper/outer arm. It can also be damaged along its trajectory around the humerus in case of a fracture of the proximal end of the humerus or of gleno-humeral dislocation. Damage to it results in complete paralysis of the abduction of the arm (while leaving intact triggering of its movement related to contraction of the supraspinous muscle).

Radial Nerve

This is a mixed nerve and the nerve of extension (elbow, wrist, fingers). It is formed of fibres which emerge from roots C5 to T1. As the terminal branch of the posterior cord in the brachial plexus, it leaves the axillary fossa, passing under the teres major, and gives rise to its first collaterals. It continues caudally, dorsally and laterally, penetrates into the posterior compartment of the arm via the triangular space to reach the spiral groove of the humerus. The nerve goes around the humerus to lie at the lateral aspect of the arm. In its brachial trajectory, it is in contact with the bone along 8–10 cm in length. It crosses the lateral intermuscular septum at 10–12 cm above the elbow joint interline to pass into the anterior compartment of the arm, where it leads into the lateral bicipital groove. Up until this level, it gives rise to the following collateral branches:

- Posterior cutaneous nerve of the arm.
- Nerve of the long head of the triceps muscle.
- Upper nerve of medial head of triceps muscle.
- Lower nerve of medial head of triceps muscle (or nerve of medial head and of the anconeus).
- Nerve of lateral head of triceps muscle, inferior lateral cutaneous nerve of the arm.
- Nerve of the brachioradialis muscle.
- Nerve of the extensor carpi radialis longus muscle.
- Posterior cutaneous nerve of the forearm; at the emergence from the radial groove, this sensory branch detaches and, after emerging in the subcutaneous plane in the lateral border of the tendon of the triceps muscle, continues between the lateral epicondyle and the olecranon process, before it branches to provide the sensation of the posterior aspect of the forearm.

At the lateral epicondyle, the radial nerve divides into its two terminal branches:

- The superficial branch, solely sensory, descends vertically against the deep aspect of the brachioradialis muscle, accompanied by the radial artery, to arrive, in the lower third of the forearm, in the posterior antebrachial area by superficially crossing the tendon of the brachioradialis muscle. It provides sensation to the lateral aspect of the back of the hand located outside of a line passing through the axis of the third finger, except for the middle and distal phalanges of the second and third fingers.
- The deep branch, mainly motor, passing between the two heads of the supinator muscle, and then emerging in the dorsal compartment of the forearm between the two muscle planes where it divides into its terminal branches. Other than the posterior antebrachial interosseous nerve, which descends up to the dorsal aspect of the carpus that it innervates, it gives rise to motor branches of the following muscles:
  extensor carpi radialis brevis
  supinator
  extensor digitorum
  extensor digiti minimi
  extensor carpi ulnaris
  abductor pollicis longus
  extensor of pollicis longus
  extensor indicis
  extensor pollicis brevis

Characteristic signs of damage to the radial nerve, depending on level of the lesion, are paralysis of extension of the forearm, the wrist, the fingers, with anaesthesia reaching all or part of the posterior aspect of the arm, the forearm and the area of the back of the hand located outside of a line passing through the axis of the third finger (apart from the middle and distal phalanges of this same digit and of the index finger).

Musculocutaneous Nerve

The musculocutaneous nerve is a mixed nerve. Comprised of fibres from C5 and C6, it arises from the lateral cord of the brachial plexus in the axillary region. It passes through the coracobrachialis muscle and continues caudally and laterally. It travels between the biceps brachialis and the brachialis muscle. It emerges at the inferior part of the arm in the lateral bicipital groove, between the brachioradialis muscle and the biceps brachii muscle. It passes through the brachial facia, becomes subcutaneous, thus comprising the lateral cutaneous nerve of forearm, and gives rise to its two terminal branches:

– Ventral, which supplies skin sensation to the lateral part of the ventral aspect of the forearm and the lateral half of the elbow fold
– Dorsal, which is responsible for dorsal and lateral forearm skin sensation

In its brachial trajectory, the musculocutaneous nerve gives rise to the:

– Diaphyseal nerve of the humerus
– Generally two branches of the coracobrachialis muscle
– The vascular bundle for the brachial artery
– The nerve of the biceps muscle (one branch for each head)
– The nerve of the brachialis muscle
– An articular branch for the elbow joint

Signs of nerve lesion (or anaesthesia) in the musculocutaneous nerve are: pronation of the forearm, absent biceps contraction, an impaired ability to flex the elbow. Flexion is partially compensated by the brachioradialis and brachialis muscles, but no opposite flexion of the elbow is possible.

Median Nerve

The median nerve is a mixed nerve. It consists of fibres from C5 to C8. It is the nerve which enables flexion of the fingers and the wrist, and pronation of the forearm. It is formed by the lateral and medial cords, and arises within the axillary fossa. It descends into the brachial canal in the medial aspect of the arm, in contact with the brachial artery, describing an *S* around it (it passes from the lateral border to the ventral aspect and then to the medial border of the artery). It passes anterior to the elbow, an area where it is very exposed to injury, under the aponeurotic arch of the biceps muscle. At the elbow, it continues in the medial bicipital groove between the biceps muscle on the outside and the humeral head of the pronator teres muscle medially. At this level, it gives rise to the articular nerves for the ventral and medial aspect of the elbow and the nerve of the branching of the brachial artery. It then slides under the fibrous arch of the flexor digitorum superficialis muscle and descends in the ventral compartment of the forearm between the superficial flexor tendons which go to the second and third fingers. A few centimetres above the wrist, it separates laterally from the tendons of this muscle and becomes superficial; it then passes along the inner aspect of the tendon of the flexor carpi radialis muscle. It then enters into the carpal tunnel in front of the tendon of the flexor digitorum superficialis muscle and, at its emergence in the tunnel, it divides into a motor branch for the thenar eminence (abductor pollicis brevis, opponens pollicis and flexor pollicis brevis muscles) and the two lateral lumbrical muscles, and a sensory branch which gives rise to the common palmar digital nerves 1, 2 and 3. The motor and sensory nerves can anastomose with the ulnar nerve.

The median nerve gives rise to the following collateral branches:

– Nerve to the brachial artery
– Articular branch to the elbow
– The nerve of the medial epicondylar muscles (flexor carpi radialis, palmaris longus, flexor digitorum superficialis, ulnar head of the pronator teres)
– The anterior antebrachial interosseous nerve (flexor pollicis longus, the two lateral heads of the flexor digitorum profundus, the pronator teres muscle and the wrist joints)
– The palmar branch of the median nerve

From a sensory perspective, the median nerve supplies the lateral part of the palm of the hand (except for the lateral part of the thenar eminence where the radial nerve participates) and the palmar aspect of fingers 1–3, as well as the lateral half of the fourth finger. On the dorsal aspect, it provides sensation for the proximal and middle phalanges of fingers 2 and 3 and the lateral half of phalanges 2 and 3 of the 4th finger.

The median nerve forms connections in the arm with the musculocutaneous nerve, and in the forearm with the ulnar nerve and radial nerve (influencing innervation of the thenar eminence/thumb). The existence of these anastomoses and articular branches explains the need to block the median nerve more often than its cutaneous distribution would suggest.

It should be noted that it is the nerve which presents the largest number of anatomical variations, difficult to present and summarise in this description.

Ulnar Nerve

The ulnar nerve is a mixed nerve. It arises from C8 to T1, emerges from the axillary fossa and ends in the hand. The terminal branch of the medial cord of the brachial plexus descends first between the brachial artery and vein. In the axillary area, it is deep, located at the medial aspect of the artery. In the middle part of the arm, it penetrates the medial intermuscular septum, thus going from the anterior brachial compartment to the posterior brachial compartment, in contact posteriorly with the medial head of the triceps muscle. In the dorsal medial aspect of the elbow, it passes superficially into the medial epicondyle-olecranon groove. Like the median nerve, it does not give rise to any collaterals in the arm, but provides an articular branch for the elbow. It enters the forearm by passing between the two heads of the flexor carpi ulnaris muscle, to which it gives a muscular branch. In the upper two-thirds of the forearm, it passes on the medial aspect and then the ventral aspect of the flexor digitorum profundus, covered by the flexor carpi ulnaris in the lateral aspect of which it positions itself. The ulnar nerve is joined at the mid-portion of the forearm by the ulnar artery, which lies laterally. It then descends into the ventral compartment of the forearm up to the wrist, where after penetrating the antebrachial fascia, it continues into the ulnar tunnel accompanied by the ulnar artery.

Its collateral branches are:

- Articular branches for the posterior aspect of the elbow
- Muscular branches for the flexor carpi ulnaris muscle and the medial half of the flexor digitorum profundus muscle
- The dorsal branch of the ulnar nerve which arises in the lower one-third of the forearm and after reaching the posterior aspect of the wrist, gives rise to the medial and lateral dorsal digital nerves of the fifth and fourth digits, and the medial dorsal digital nerve of the third digit
- The palmar branch which innervates the skin of the hypothenar eminence

Its terminal branches separate at the end of the ulnar canal and are represented by:

- A mixed superficial branch, innervating the palmar muscles and which provides complete palmar sensitivity to the fifth digit and medial sensitivity to the fourth digit
- A deep branch, in contact with the skeleton, which divides into several branches to innervate the eight interosseous muscles, the third and fourth lumbricals and a few muscles of the thenar eminence (adductor pollicis and deep head of flexor pollicis brevis) where there is a possible anastomosis with the medial nerve

Its motor function is not essential in the forearm, where it innervates few muscles. It is essential in the hand, where it innervates the largest part of the muscles, apart from the first and second lumbricals, opponens pollicis, the superficial head of flexor pollicis brevis and the abductor pollicis brevis muscles, which are innervated by the median nerve.

In terms of sensory function, the ulnar nerve, by its hypothenar branch, innervates the palmar aspect of the fifth finger and the palmar medial course of the fourth digit. By its dorsal branch, it innervates the dorsal aspect of the fifth finger, the dorsal aspect of the first phalanx and of the medial half of the second and third phalanges of the fourth digit, as well as the dorsal aspect of the medial half of the first phalanx of the third digit.

Medial Cutaneous Nerve of the Arm

This is a small sensory nerve and which innervates the axillary fossa and overlaps a little on the medial aspect of the arm and the chest wall. The second collateral branch of the medial cord of the brachial plexus arises from T1. It forms an anastomosis usually with the intercosto-brachial nerve, which does not belong to the brachial plexus and which arises from the lateral perforating branches of the first two intercostal nerves (T1-T2), sometimes also from the third one (T3).

Medial Cutaneous Nerve of the Forearm

The third collateral branch of the medial cord of the brachial plexus is a sensory nerve which arises from C8-T1. In the medial part of the arm, it continues superficially beside the basilic vein. Starting from the upper third of the arm it gives rise to the sensory perforating branches, crosses the aponeurosis in the lower one-third and becomes superficial at the elbow. It provides sensory innervation of the medial half of the lower two-thirds of the arm and the medial half of the forearm.

Although the medial cutaneous nerve of the forearm generally is anaesthetised during conduct of a brachial plexus nerve block in the axillary fossa or in the humeral tunnel, the subcutaneous portion of the medial cutaneous nerves in the arm and the medial cutaneous nerve of the forearm make them accessible to subcutaneous injection.

Brachial Plexus Nerve Blocks

Anaesthesia of the nerves of the brachial plexus can be planned in the plexus area strictly speaking (interscalene, supraclavicular and infraclavicular nerve block) (Fig. 5.9), where it can be considered that a single injection may effectively block the entire upper limb. This is not exactly the case, since both in the interscalene and supraclavicular level, there is a significant incidence of block failure in the C8-T1 distribution [4]. This is less common in the infraclavicular approach which generally enables anaesthesia of all areas of the distal half of the arm up to the end of the fingers [5]. Approaching the plexus more distally, because of the divergence of the terminal branches of the plexus, in order to anaesthetise an equivalent area, it is necessary to administer separate, targeted nerve blocks. This is the basis of multistimulation techniques with the infraclavicular and axillary approaches [6, 7].

In deciding which type of nerve block is to be performed (which depends on the indication and the desired extent of anaesthesia), it is desirable to consider those for which discomfort for the patient and iatrogenic harm are the lowest. Therefore, insofar as possible, the practitioner will strive to limit the number of injections necessary and will choose the approaches which present the fewest risks.

For all brachial plexus nerve blocks, in practice it is possible to perform either a single block or a continuous block with placement of a perineural catheter. The expected result should take into account the anatomical specific aspects of each site. If a catheter for analgesia is inserted during an axillary block, depending on the precise place where it is located, its efficacy may be manifested only in the area of the radial and/or ulnar nerve, or indeed the median nerve, or even the musculocutaneous nerve. And if in the initial phase of the block, an injection of a local anaesthetic is administered to all of the nerves, initial overall efficacy will be followed subsequently by more selective anaesthesia or analgesia, depending on the precise site of distribution of the low flow of local anaesthetic through the catheter. This process should be thoroughly understood in order to guide positioning of the tip of the catheter so that the latter is placed in proximity to the nerve(s) for which prolonged anaesthesia is desired after regression of the initial block. During injection through a catheter, spread of the local anaesthetic occurs via the openings of the catheters; some catheters have a single perforation (end), others multiple perforations (along the last centimetres). Therefore, spread of the anaesthetic can take place over a certain length of the catheter starting from its end. This is all the more so when retrograde spread of the local anaesthetic occurs (called backflow) along the course of the catheter. This should be used and exploited advantageously in the strategy for placement of the catheter. For example, also in the axillary area, to achieve the most effective block of the brachial plexus while using a multiperforated catheter, it may be possible to insert it in contact with the different target nerves in order to guide the backflow of the local anaesthetic.

Interscalene Block (Fig. 5.10)

Indications

An interscalene block (ISB) is recommended for anaesthesia and post-operative analgesia in shoulder surgery [8]. In fact, the analgesic potency that it provides is the most appropriate to this type of surgery, with high levels of satisfaction and excellent tolerability by patients. Alternatives to this block in the presence of a contraindication are, by order of efficacy on post-operative pain, a suprascapular block (with or without an axillary nerve block), a subacromial injection, and lastly by patient-controlled analgesia (PCA) with intravenous morphine [9, 10]. The volumes of local anaesthetics used have been greatly decreased as a result of ultrasound-guided technique [11, 12].

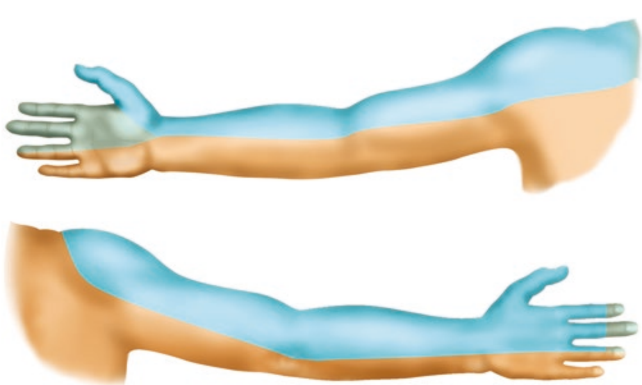


Fig. 5.10 Area of coverage of an interscalene block

Although the time necessary for conduct of an ISB is slightly longer than that of general anaesthesia, the time for installation and emergence from the OR are shortened, as well as duration of stay in the post-operative recovery room and hospital stay in ambulatory arthroscopic surgery. This block is not indicated for distal surgery of the upper limb, even by deep injection of the local anaesthetic, in the lower roots of the brachial plexus. Ilfeld's team demonstrated that only 15% of patients obtained a surgical block of the hand and the forearm 30 min after conduct of an ISB [13].

Conduct of an interscalene block is not a contraindication to ambulatory surgery [14, 15]. This block is used essentially in arthroscopies, for which low doses of local anaesthetics are sufficient to improve post-operative analgesia (10 mL of 0.5% ropivacaine according to Krone et al. [15]).

It is possible to perform an interscalene block with a single injection or to insert a perineural catheter, ideally with use of a PCA pump (patient-controlled analgesia) connected to the catheter, which improves the quality and increases the duration of post-operative analgesia [16–19]. This is the case for procedures where predictable "VAS" (visual analogue scale) scores are greater than 3 and where duration of post-operative pain exceeds 24 h, i.e. repair of the rotator cuff, arthrolysis, a shoulder block, shoulder arthroplasty (prosthesis), fracture of the humeral head and tumours. Although it was frequently said that shoulder arthroscopy was not painful, advances in surgical techniques have led to the indication with use of a catheter in the majority of therapeutic arthroscopies. In fact, currently many repair procedures for shoulder surgery are performed with arthroscopy: rotator cuff rupture, Bankart repair, bone blocks, acromioplasties, arthrolysis and tendonplasty. A catheter can also be inserted for certain physical therapy procedures or for cancer-related pain [20].

Continuous interscalene block (interscalene catheter) can also be part of an analgesic strategy enabling ambulatory surgery of the shoulder, including complicated surgery [21–24].

Type of probe: linear, 5–10 MHz or 6–13 MHz.
Axis of probe: transverse (Fig. 5.11a, b).
Configuration: nerves in the small axis, needle in the plane.
Studied depth: 2–4 cm.
Neurostimulation: enables further identification of the nerves visualised and can limit, by determination of an MIS > 0.3 mA (0.1 ms), the risk of accidental intrafascicular injection. Furthermore, it can supplement locating nerves when conditions of visibility are unfavourable.
Needle: 50–80 mm isolated, 22G.
Utility of Doppler ultrasound: cardiac, internal jugular, vertebral artery and vein that can be encoun-

tered at the tip of the needle, sometimes blood vessels within the interscalene area (transverse cervical artery which may be encountered inconsistently, ascending cervical artery).

Approach, Ultrasound Anatomy

Two principal approaches can be described for an interscalene block with a single injection or for insertion of a perineural catheter: posterolateral (in plane) and in the axis of the interscalene groove (out of plane).

Posterolateral Approach (In Plane) (Fig. 5.12)

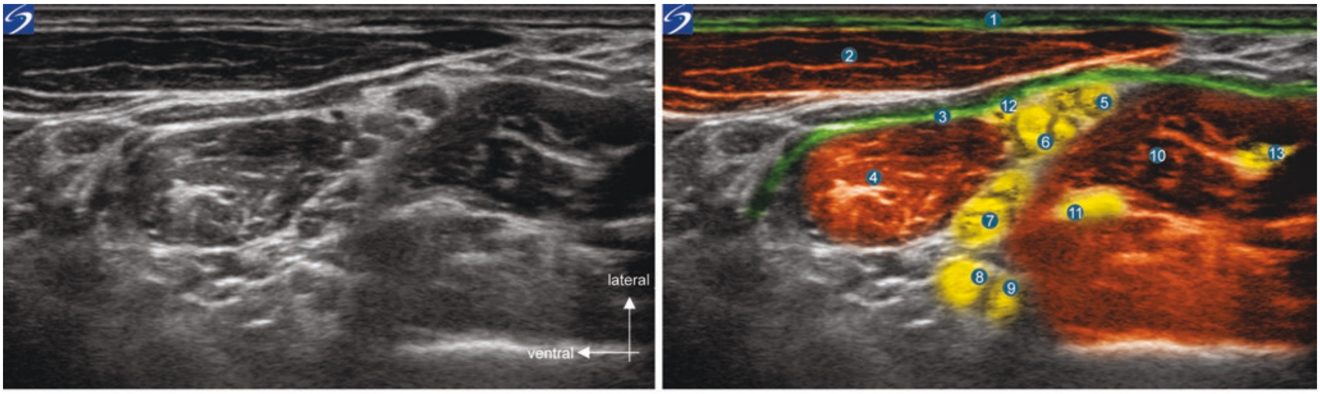
This is the preferred approach when performing interscalene brachial plexus block. Although not routinely adopted when using the traditional landmark/neurostimulation technique, when using ultrasound it offers the optimal view of the underlying anatomy, the needle approach to components of the plexus and for visualising the spread of local anaesthetic.

Nerve Localisation

The head is turned to the opposite side to relax the interscalene portion of the sternocleidomastoid muscle. Finding the optimum injection site is achieved by moving the probe along the interscalene groove to indentify, in a single view in the ultrasound plane, the nerve roots C5 and C6 (or their branches of ventral and dorsal division) and C7 root (middle trunk) which lies at the centre of the brachial plexus (Figs. 5.13, 5.14, and 5.15). Accurate identification of the nerve roots is based on presence and shape of the cervical transverse processes. Transverse processes of C3-C6 have an anterior and posterior tubercle (Figs. 5.16, 5.17, 5.18, and 5.19). However, the C7 transverse process has only a single posterior tubercle (Fig. 5.20) and thus is readily differentiated from the others. This enables identification of the cervical nerve roots [25]. When it is possible to differentiate C8 more in depth, the upper and middle trunks divided into the ventral and dorsal branches (as well as structures corresponding to the collateral branches of the plexus) are seen on

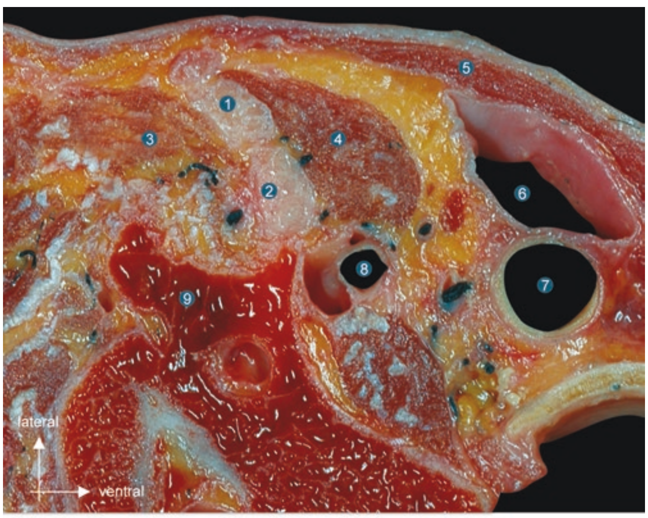
Fig. 5.12 Ultrasound-guided interscalene block. Needle insertion in-plane

Fig. 5.11 Cervical transverse section at the level of C6 with materialisation of the ultrasound beam. Position of the probe



1. superficial layer of cervical fascia
2. sternocleidomastoi m.
3. C5 n. root
6. C6 n. root
7. C7 n. root
8. C8 n. root
9. T1 n. root
10. middle scalene m.
11. long thoracic n.
12. phrenic n.
13. dorsal scapular n.

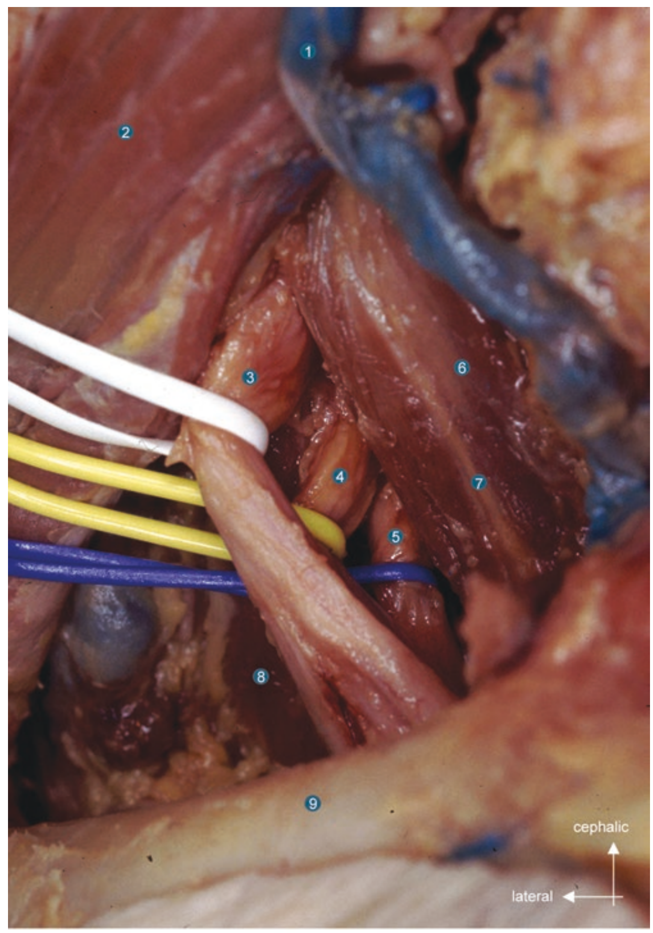
Fig. 5.13 Low transverse ultrasound section of the interscalene area



1. C5 and C6 n. roots
2. C7 n. root
3. middle scalene m.
4. anterior scalene m.
5. sternocleidomastoid m.
6. internal jugular v.
7. common carotid a.
8. vertebral a.
9. transverse process of C7 vertebra

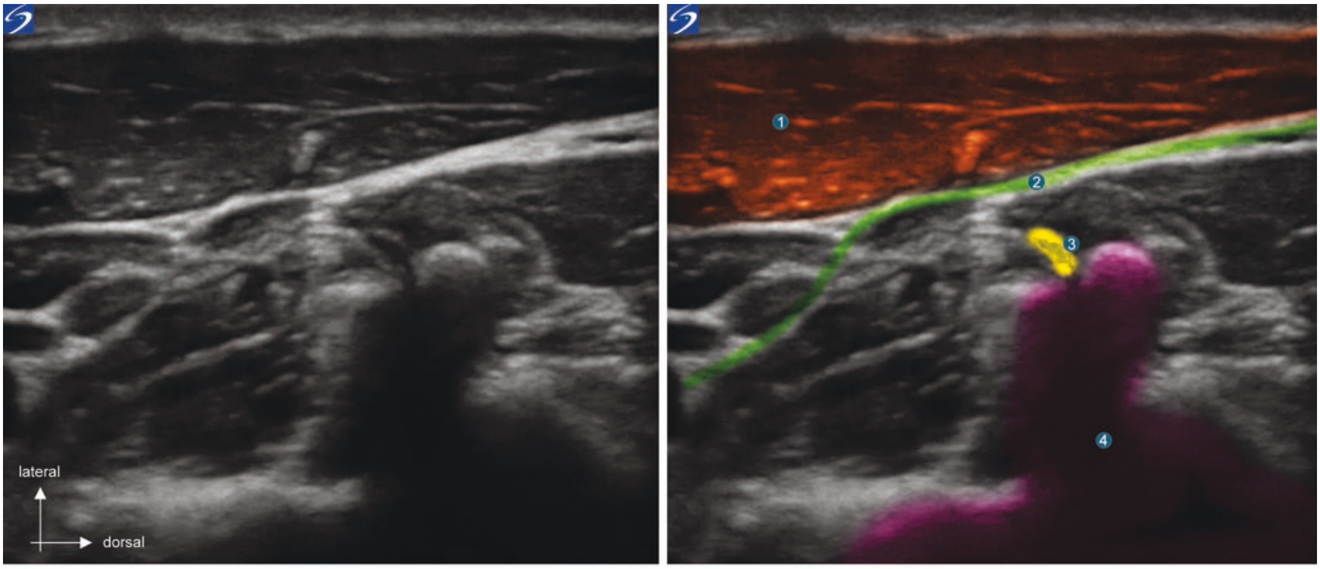
Fig. 5.14 Transverse section passing through transverse process of C7. (Iconography: Admir Hadzic)

superficial level of the interscalene space (Fig. 5.13). Under good conditions, the phrenic nerve can be identified lying on the lateral aspect and then the ventral aspect of the anterior scalene muscle (Figs. 5.13 and 5.21). The suprascapular nerve can be seen to lie on the lateral aspect of the middle scalene muscle which separates from the brachial plexus, by continuing dorsally (Fig. 5.22). The dorsal nerve of the scapula can also be found along with the long thoracic nerve passing through or crossing the body of the middle scalene muscle (Figs. 5.9, 5.13 and 5.23).



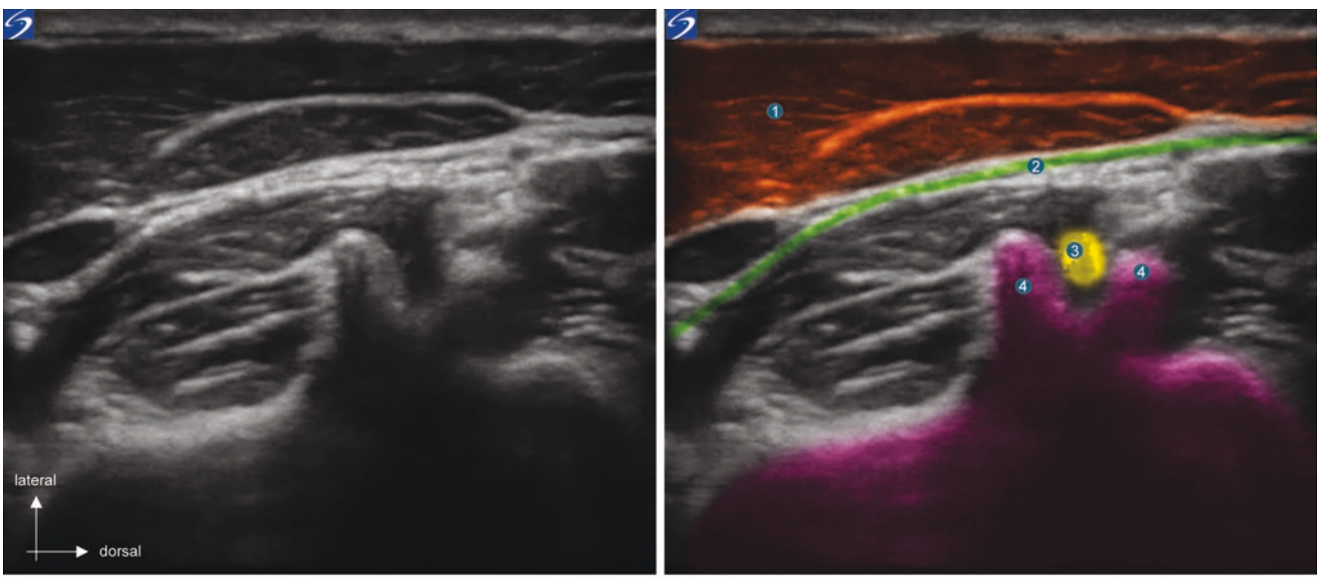
1. external jugular v.
2. sternocleidomastoid m.
3. C5 n. root
4. C6 n. root
5. C7 n. root
6. anterior scalene m.
7. phrenic n.
8. middle scalene m.
9. clavicle

Fig. 5.15 Brachial plexus at the interscalene level. (Dissection: Bertrand Fabre)



1. sternocleidomastoid m. 2. prevertebral layer
3. C3 n. root 4. transverse process of C3

Fig. 5.16 Transverse ultrasound section of neck at the level of the transverse process of C3



1. sternocleidomastoid m. 2. prevertebral layer 3. C4 n. root
4. anterior and posterior tubercles of transverse process of C4 vertebra

Fig. 5.17 Transverse ultrasound section of neck at the level of the transverse process of C4

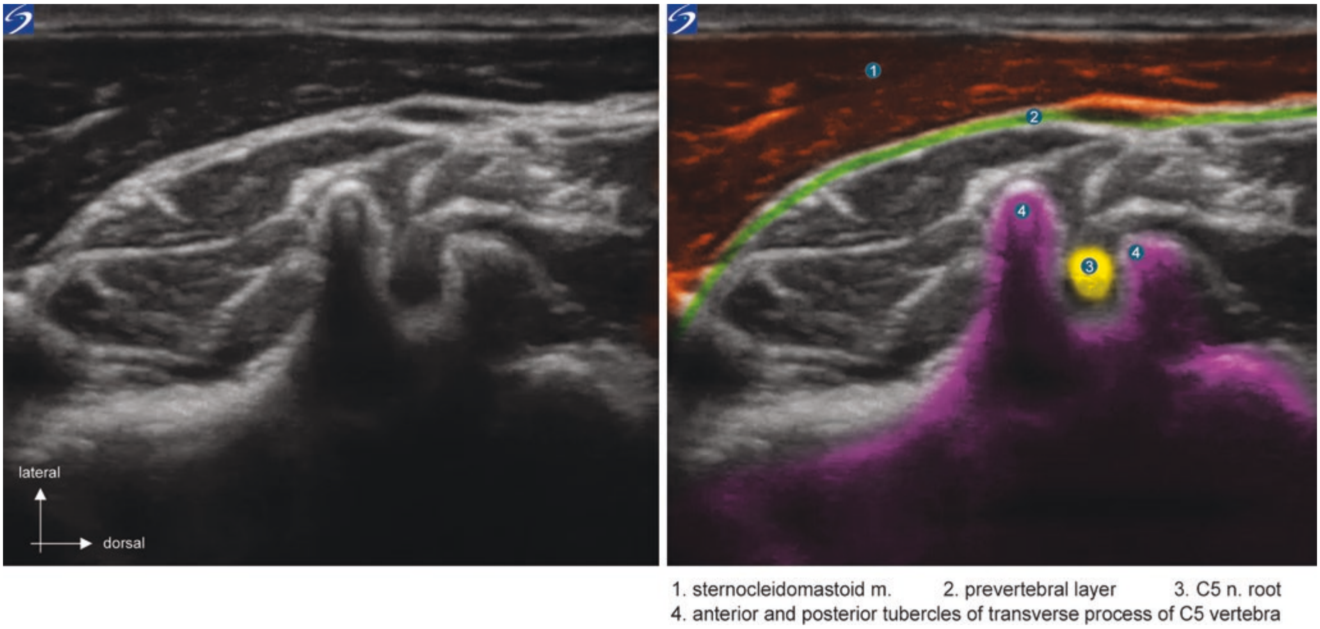


Fig. 5.18 Transverse ultrasound section of neck at the level of the transverse process of C5

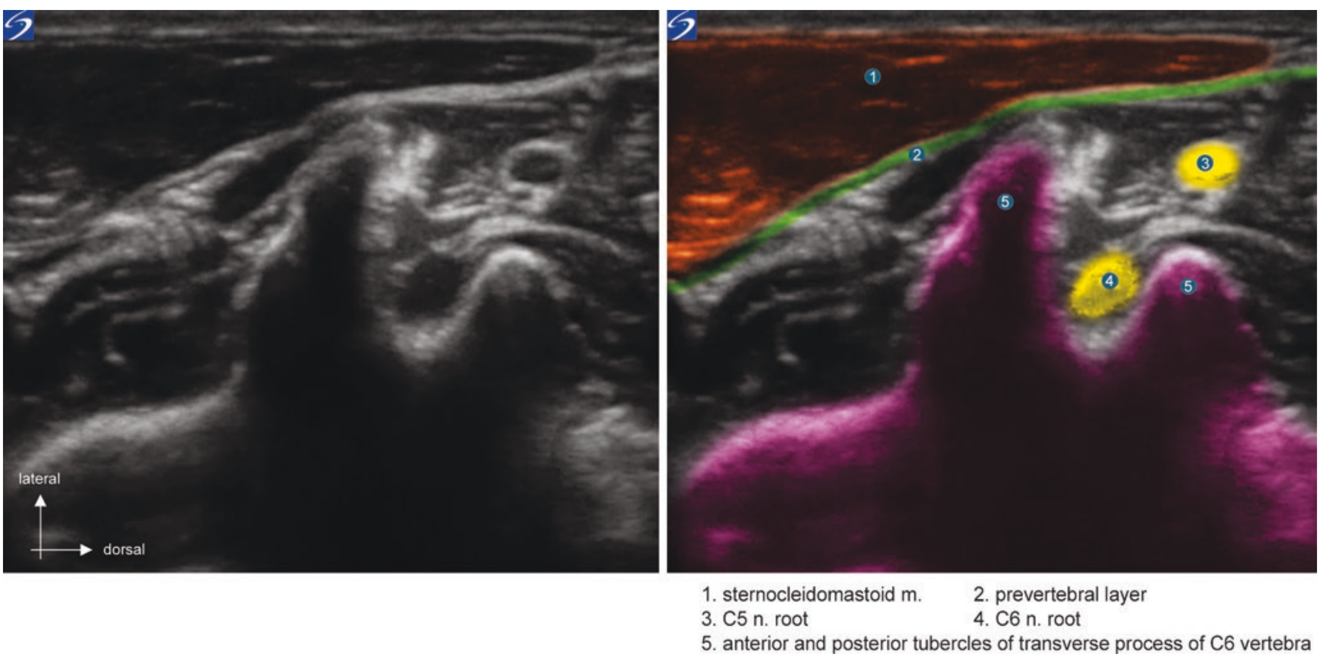
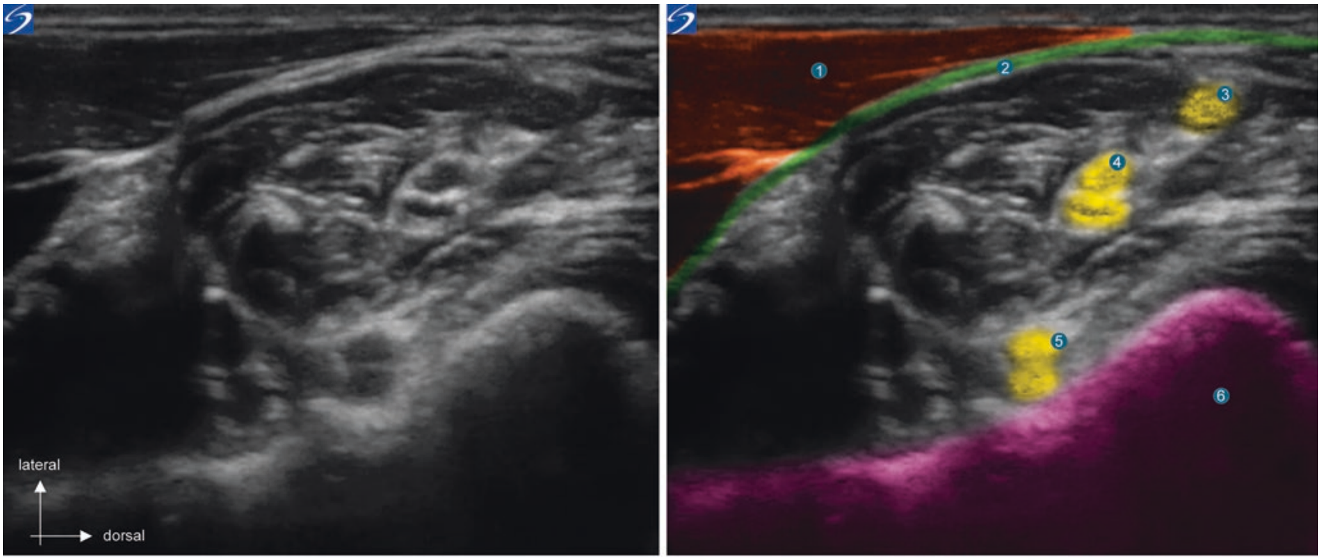
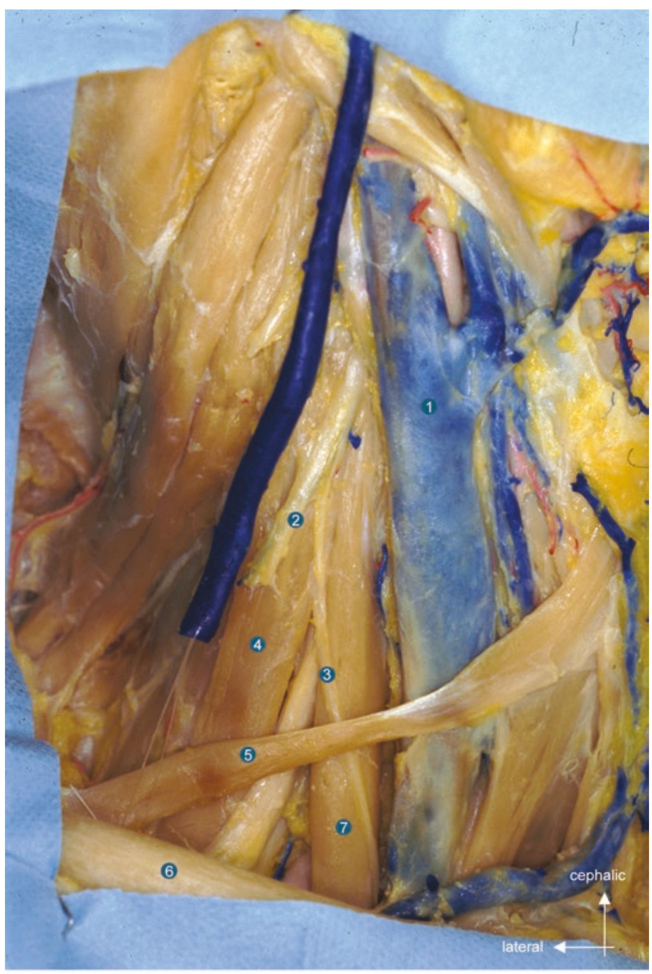


Fig. 5.19 Transverse ultrasound section of neck at the level of the transverse process of C6



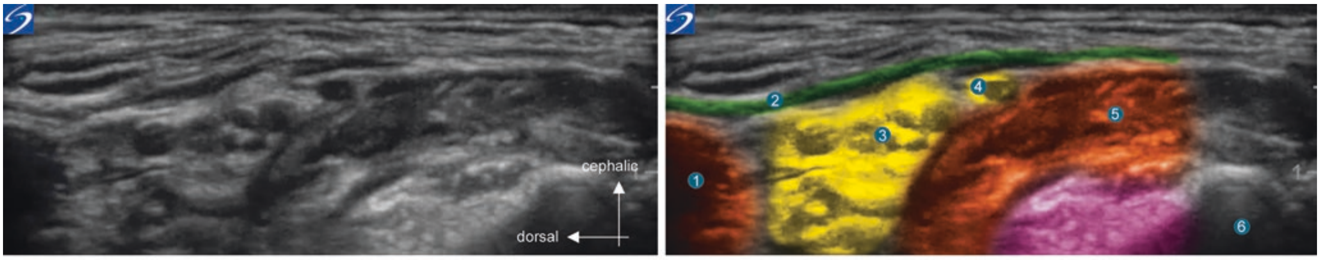
1. sternocleidomastoid m.
2. prevertebral layer
3. C5 n. root
4. C6 n. root
5. C7 n. root
6. posterior tubercles of transverse process of C7 vertebra

Fig. 5.20 Transverse ultrasound section of neck at the level of the transverse process of C7



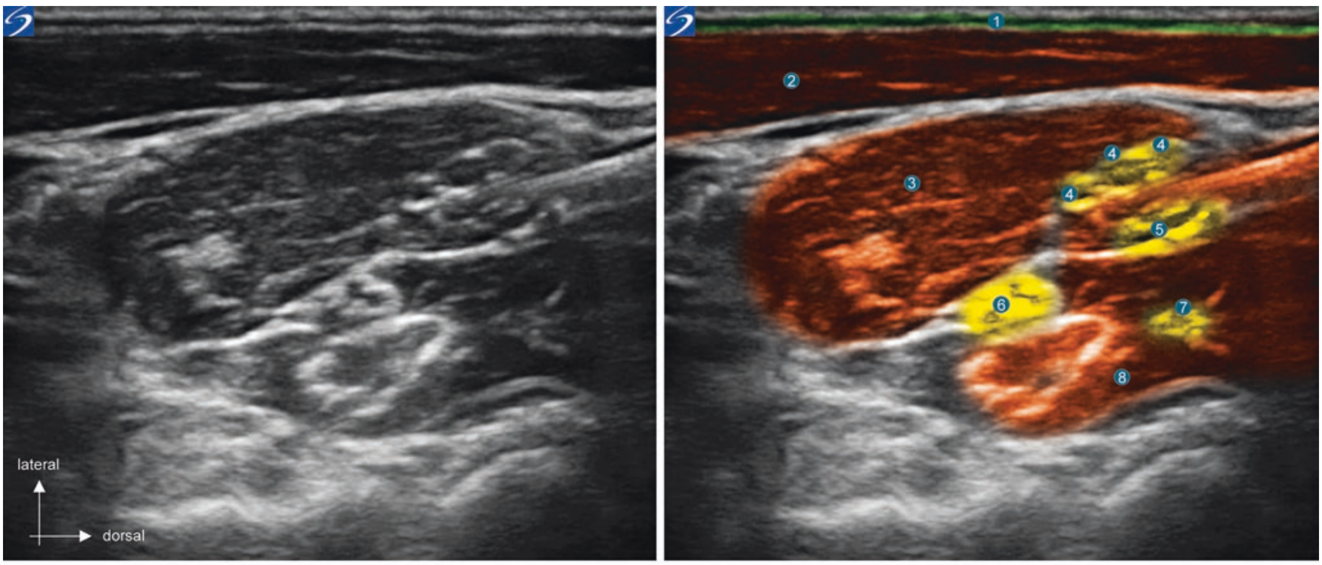
1. internal jugular v.
2. suprascapular n.
3. phrenic n.
4. middle scalene m.
5. omohyoid m.
6. clavicle
7. anterior scalene m.

Fig. 5.21 Lateral aspect of the neck, sternocleidomastoid muscle. (Dissection: Bertrand Fabre)



1. anterior scalene m.
2. prevertebral layer
3. branchial plexus (upper and middle trunk, collateral branches)
4. suprascapular n.
5. middle scalene m.
6. first rib

Fig. 5.22 Position of the suprascapular nerve on the surface of the middle scalene muscle, coming off the rest of the brachial plexus



1. superficial layer of cervical fascia
2. sternocleidomastoid m.
3. anterior scalene m.
4. C5 and C6 n. divisions
5. dorsal scapular n.
6. C7 n. root
7. long thoracic n.
8. middle scalene m.

Fig. 5.23 Transverse ultrasound section of neck. Scapulodorsal and long thoracic nerves

The vertebral artery is an essential vascular element to positively identify during conduct of an ISB in order to avoid accidentally injuring it. In its ascending pathway, traditionally it crosses the transverse processes starting from C6 (but variations are possible in which it crosses only the transverse process starting from C5 or even C4) (Figs. 5.24, 5.25, 5.26, 5.27, 5.28, 5.29, 5.30, and 5.31).

In ultrasound-guided localization, it is possible to discover variations of the paths of the roots of the brachial plexus [26]: Fig. 5.32 shows the roots C5 and C6 (already divided) which have crossed the anterior scalene muscle to join its lateral aspect. They are very clearly separated and distant from the root of C7 which is well-placed in the interscalene pathway. Harry et al. [27] have described several types of variations in the pathway of nerve roots C5 and C6 after their emergence from the intervertebral foramina (Fig. 5.33).

Injection

The needle is inserted after infiltration of the skin with LA, at the posterior end of the probe (Fig. 5.12). It should be inserted and guided in the ultrasound plane. It should remain visible along its entire length, in a ventromedial direction in order to cross the axis of the interscalene contents. By avoiding an injection point that is too dorsal, after crossing the prevertebral lamina, the intramuscular course through the

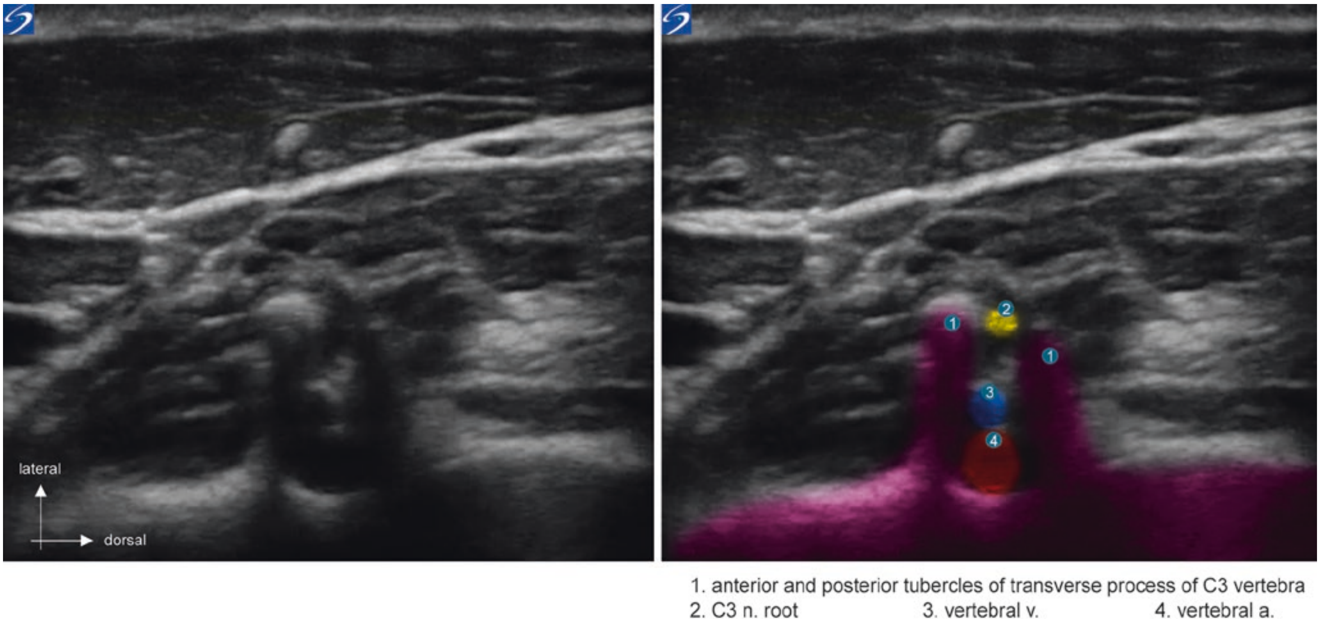


Fig. 5.24 Transverse ultrasound section passing through the transverse process of C3

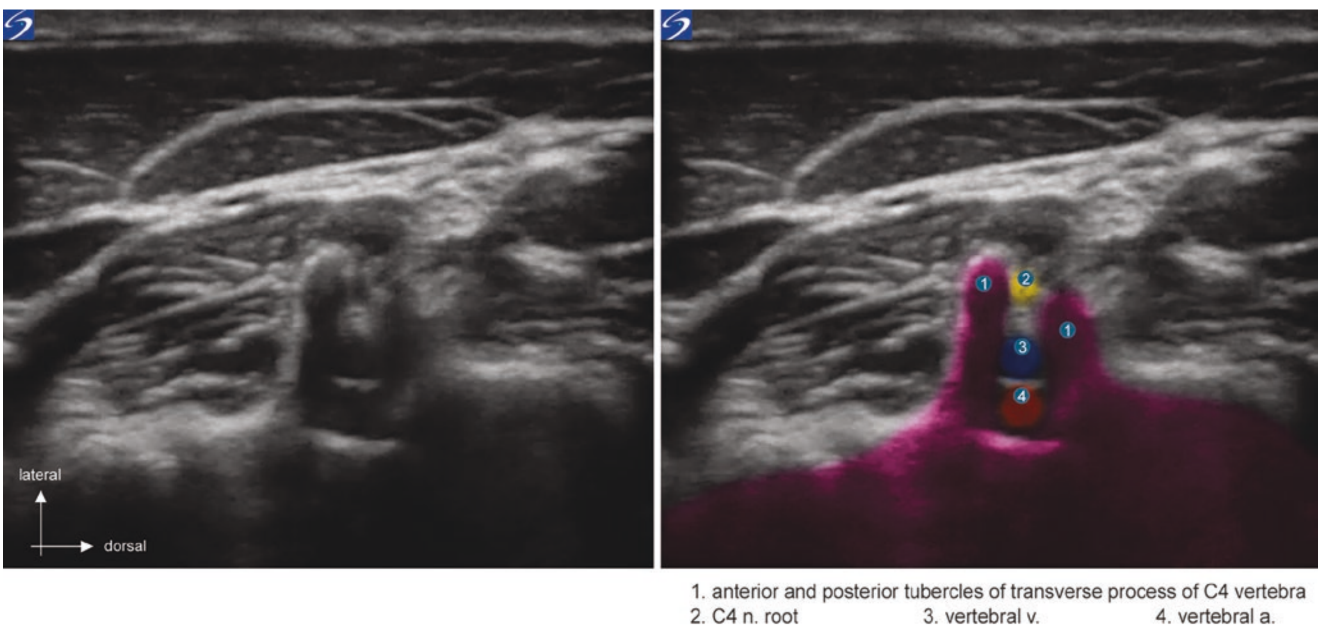


Fig. 5.25 Transverse ultrasound section passing through the transverse process of C4

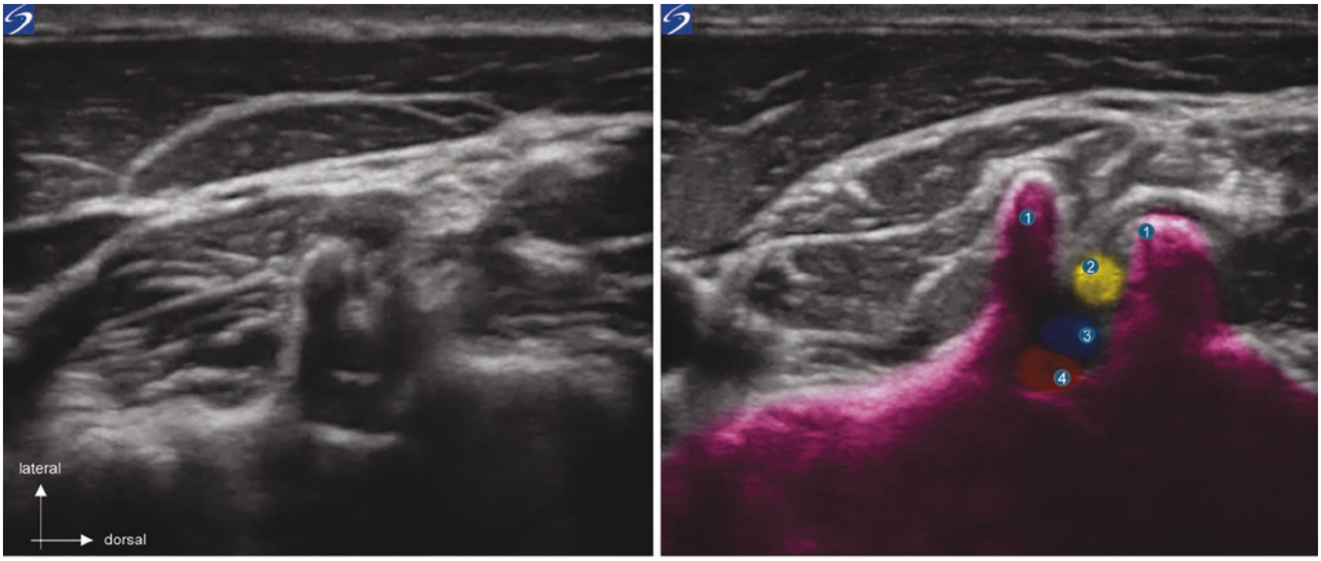


Fig. 5.26 Transverse ultrasound section passing through the transverse process of C5

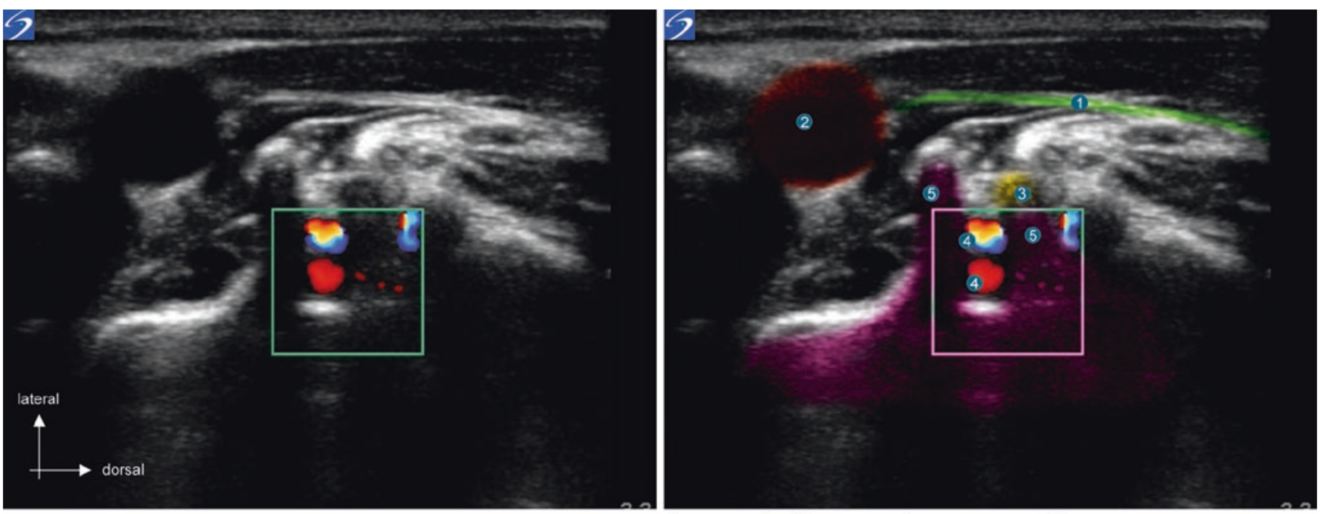


Fig. 5.27 Transverse ultrasound section passing through the transverse process of C4: Doppler signal in vertebral vessels

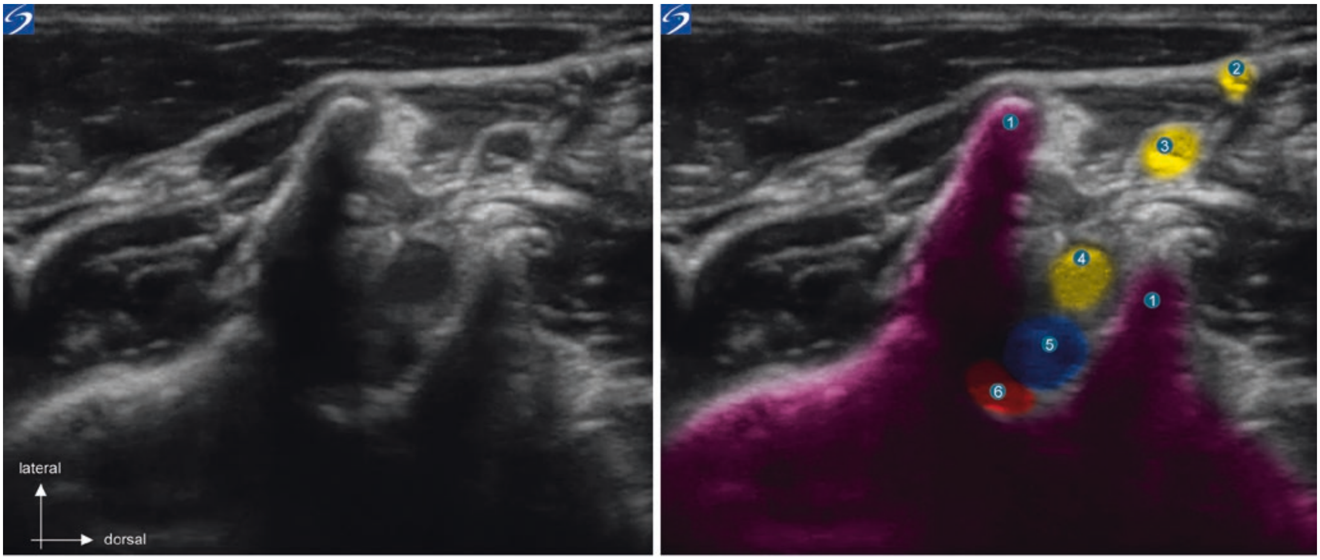


Fig. 5.28 Transverse ultrasound section passing through the transverse process of C6

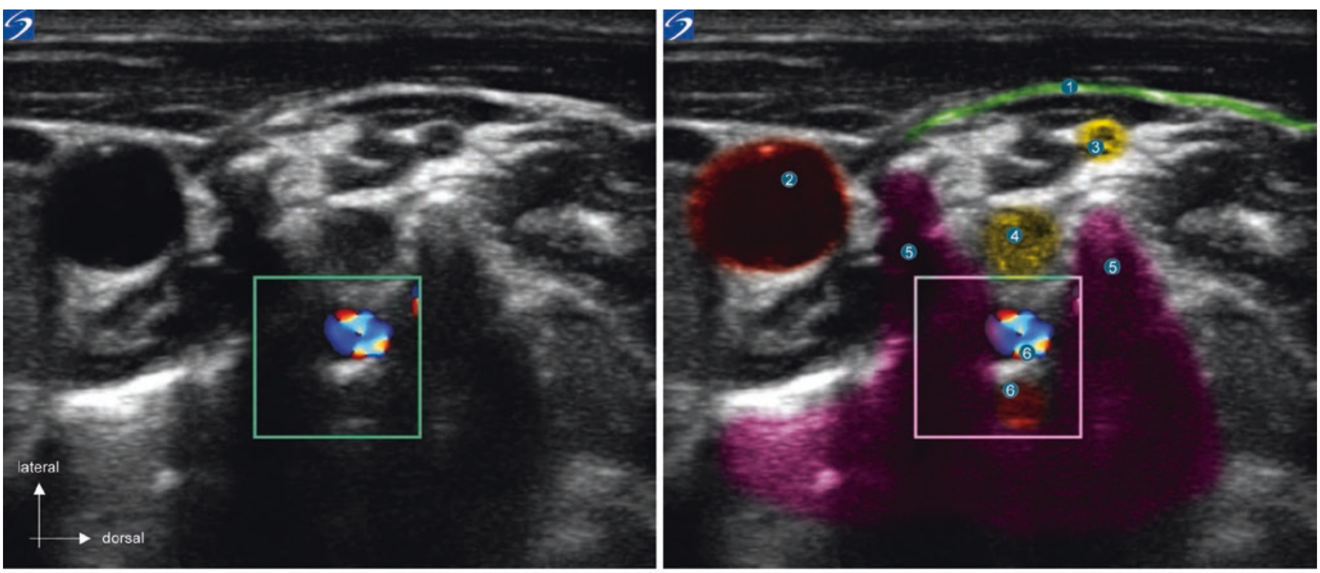
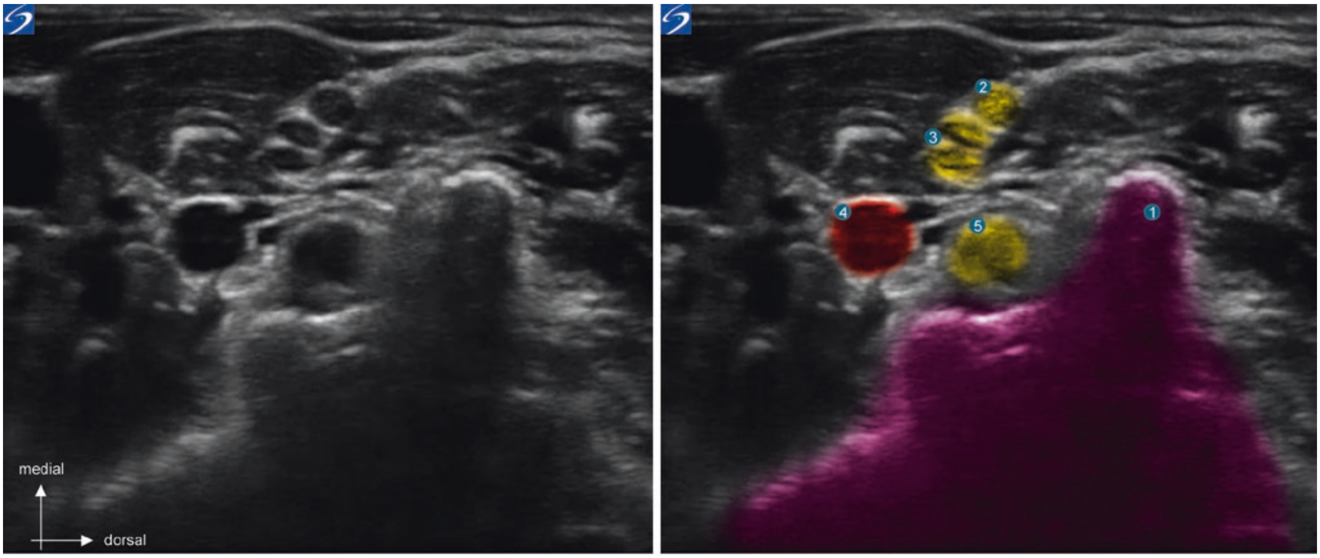


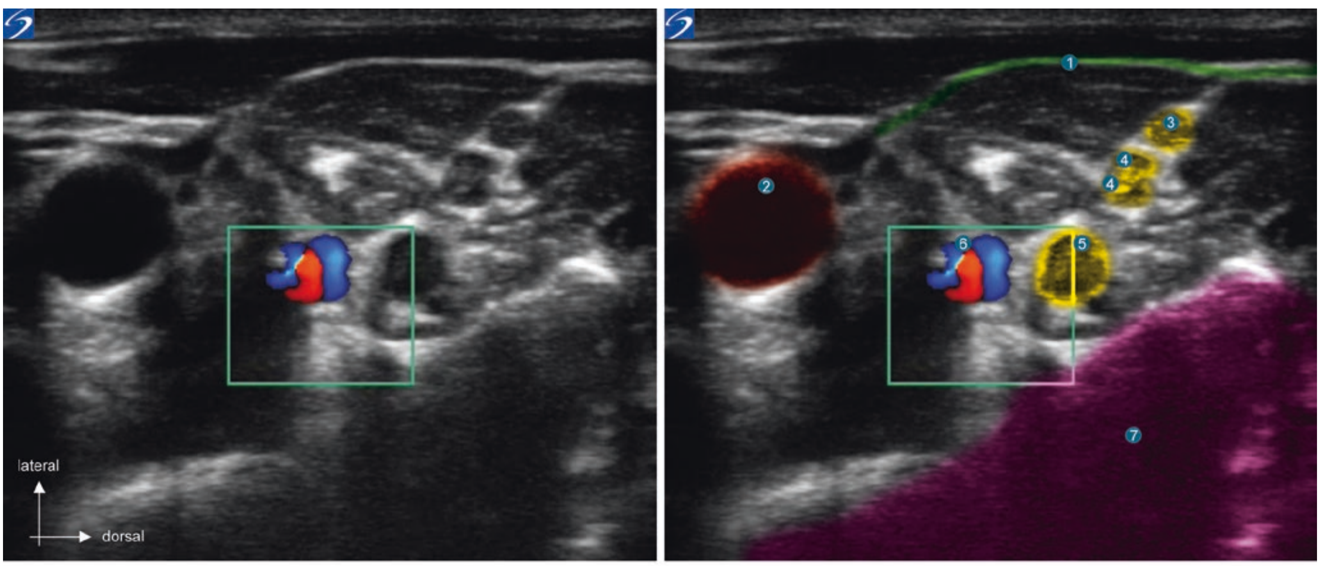
Fig. 5.29 Transverse ultrasound section passing through the transverse process of C6: Doppler signal in vertebral vessels

middle scalene muscle is limited. Thus, it is possible to progress almost parallel to the dorsal plane of the plexus, without penetrating the middle scalene muscle, while remaining in front of its anterior aponeurosis. In the final approach, it may be possible to inject a few millilitres of a D5W solution in order to perform "hydrodissection", thus facilitating ultrasound differentiation of the structures. This process also makes it possible to determine if the tip of the needle has in fact crossed the anterior aponeurosis of the middle scalene muscle. If this is not the case, we see fluid injected collect in



1. anterior and posterior tubercles of transverse process of C6 vertebra
2. C5 n. root 3. C6 n. root 4. vertebral a. 5. C7 n. root

Fig. 5.30 Transverse ultrasound section passing through the transverse process of C7



1. prevertebral layer 2. common carotid a.
3. C5 n. root 4. C6 n. root 5. C7 n. root
6. vertebral vessels 7. transverse process of C7 vertebra

Fig. 5.31 Transverse ultrasound section passing through the transverse process of C7: Doppler signal in vertebral vessels

this muscle and not in the interscalene plane. It is preferable to position the tip of the needle between roots of C6 and C7 (in proximity to the deep plane of C6) (Figs. 5.34 and 5.35). This posterolateral approach moreover offers the benefit in limiting the risk of direct traumatic injury to the phrenic nerve (sectioning by the needle). In fact, cases of persistent diaphragmatic paralysis after interscalene nerve block exist whose cause remains unclear [28–30]: toxicity of local anaesthetics, intraneural injection, direct injury to the nerve, etc. Since the phrenic nerve is not always visible with ultrasound (and thus not always "avoidable"), it is recommended to not perform ISB by approaching the plexus anteriorly while crossing the anterior scalene muscle (injection at the anterior end of the probe).

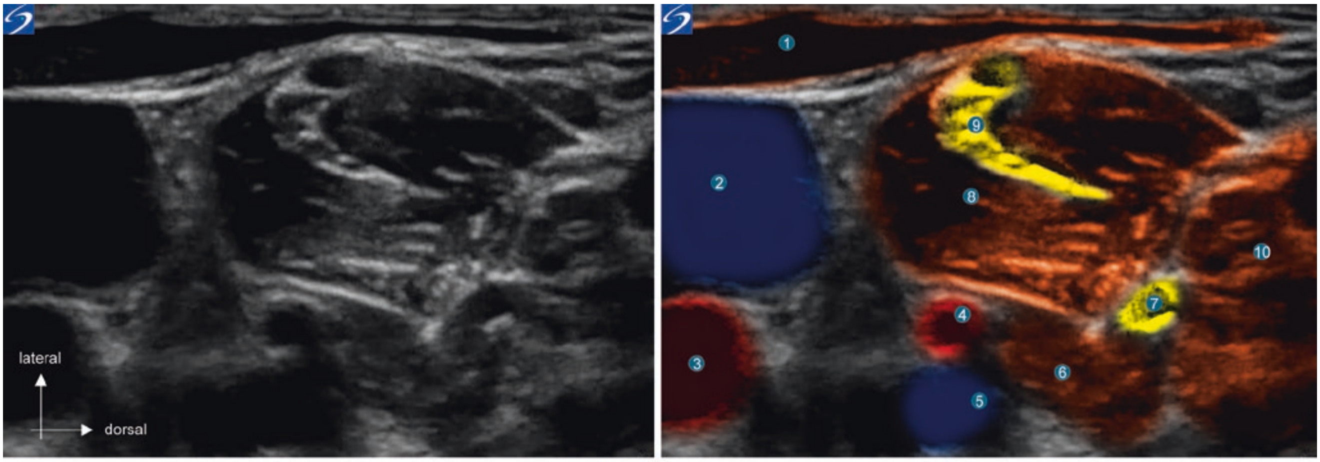
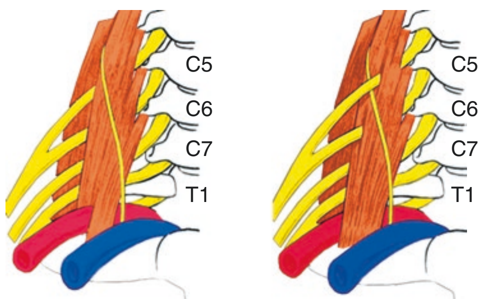


Fig. 5.32 Interscalene block. Variation in position of nerve roots: C5 and C6 (already divided) crossing the anterior scalene muscle, while C7 is located in the interscalene pathway



C5 and C6 n. roots through all the anterior scalene m.	15%
C5 n. root alone piercing the anterior scalene m.	13%
C5 and C6 n. roots piercing separately the anterior scalene m.	6%
C5 n. root in front of the anterior scalene m.	3%

Fig. 5.33 Variations in course of nerve roots C5 and C6

Interscalene Catheter by Posterolateral Approach (in the Ultrasound Plane) (Figs. 5.36, 5.37, 5.38, 5.39, 5.40, 5.41, and 5.42)

For insertion of an interscalene catheter, the injection procedure is absolutely identical to a single shot block. The objective is to position the **tip of the needle** at the place where we wish to position the **end of the catheter**. The needle trajectory should be planned to minimise tissue trauma, if possible not crossing the middle scalene muscle but without taking the risk of direct injury to the branches of the brachial plexus. Figures 5.43, 5.44, 5.45, 5.46, and 5.47 show several steps in insertion of an interscalene catheter with an injection trajectory which leaves the middle scalene muscle intact, with the tip of the needle placed in the superficial plane of C7, enabling the catheter to be placed at this level and then withdrawn slightly in order to be positioned in the deep plane of C6; as it can be seen in Fig. 5.47, the spread of the local anaesthetic is optimum around C5, C6 and partly in C7.

Injection

Direct visualisation of spread of the local anaesthetic injected enables possible repositioning of the needle in case of atypical or non-optimal spread. During the injection, the interscalene pathway "fills up" progressively with an increase in contrast of the adjacent structures (scalene muscles on both sides, nerves, aponeurosis, etc.) (Fig. 5.48). Depending on context, a volume of between 10 and 20 mL is injected.

Short/Transverse Axis Approach (Needle Out of Plane)

This approach which maintains the needle in the traditional pathway in the "anatomical" axis of the interscalene groove, in particular appears useful for insertion of a perineural catheter since it facilitates its insertion. The level of injection is

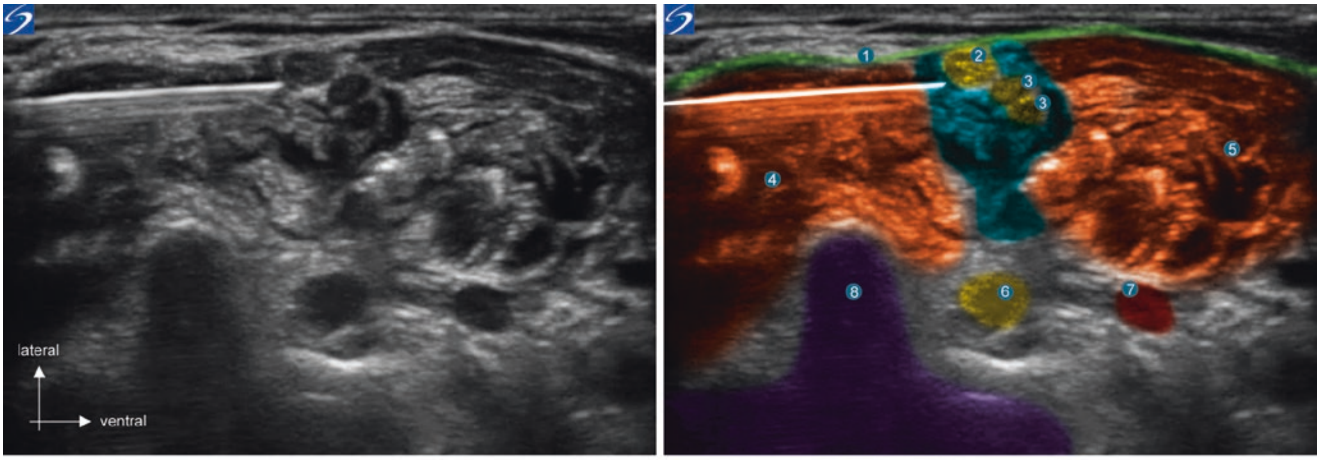


Fig. 5.34 Interscalene block. Tip of needle deep to C5

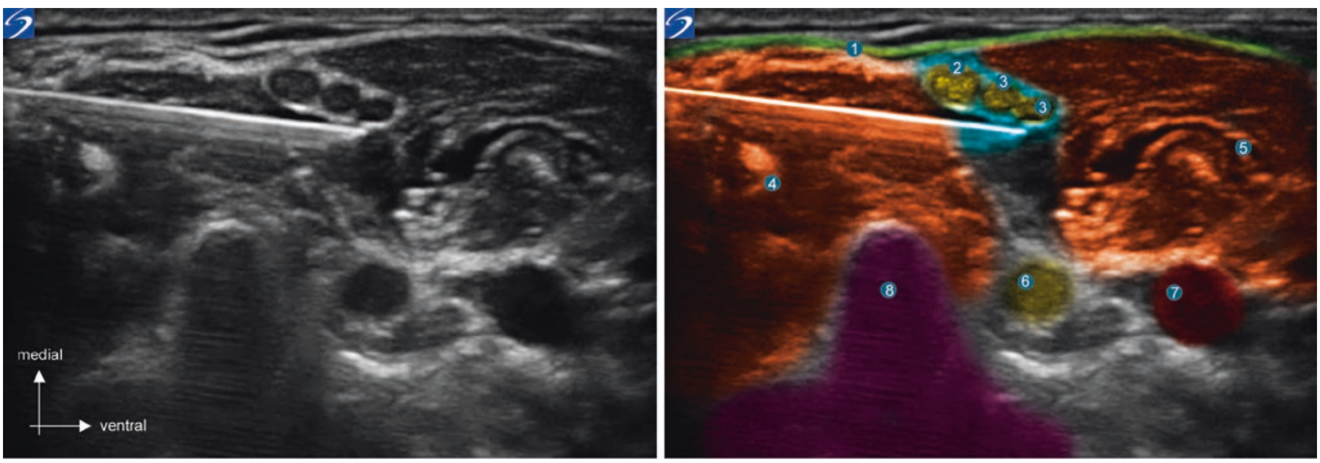


Fig. 5.35 Interscalene block. Tip of needle deep to C6

Fig. 5.36 Position of patient for placement of an ultrasound-guided interscalene perineural catheter

Fig. 5.37 Interscalene catheter: equipment

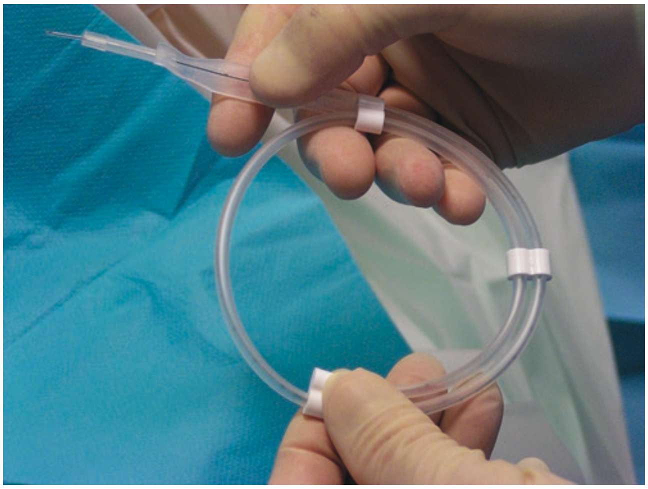


Fig. 5.38 Catheter in its introducer sheath

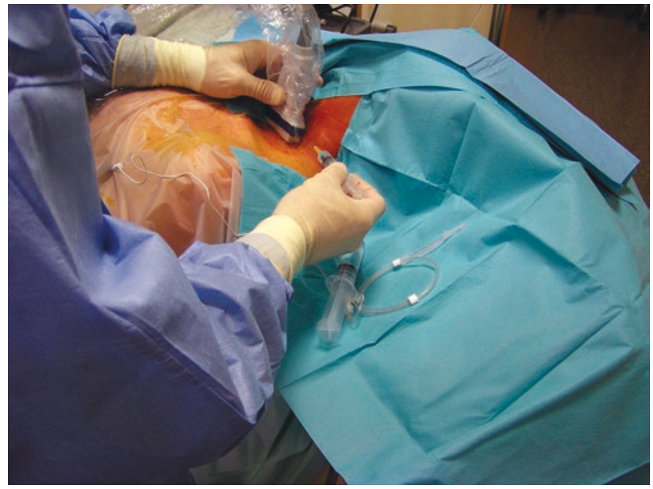


Fig. 5.40 Positioning for placement of an interscalene catheter. Injection in-plane. Initial cutaneous local anaesthesia

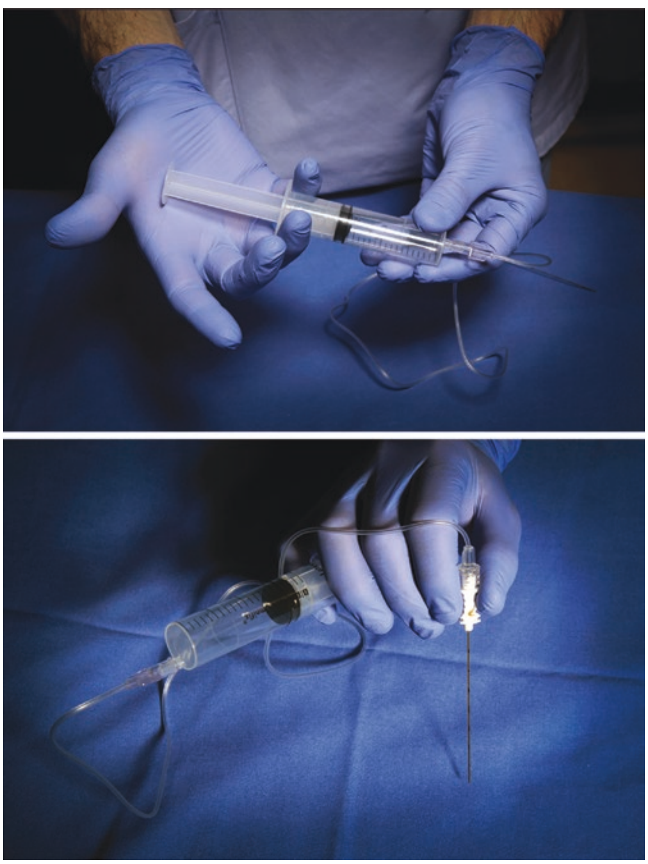


Fig. 5.39 Method of holding syringe and needle enabling needle puncture and simultaneous injection with one hand, without alternately releasing them

determined by a preliminary ultrasound scan and should not be dependent on surface landmarks alone. It is necessary to visualise the brachial plexus in a transverse section (short axis). In fact, if the probe is rotated and placed in the long axis, the structures are seen longitudinally and recognition of structures and positioning of the needle become very difficult.

This “out of plane” approach involves a transverse view and therefore only a pinpoint image of the needle, making the procedure more delicate to perform. In this configuration, control of the tip of the needle requires a cautious approach, good needle and probe control and experience with the procedure. The technique of combining neurostimulation with ultrasound reveals its advantage in especially delicate situations such as this one. The technique of hydrolocalisation is crucial during this approach. This consists of injecting successively small volumes of liquid as the needle advances, enabling the position of the needle tip to either be seen directly, or to know the plane in which it is located. The liquid injected is ideally a D5W solution in order to avoid both local and systemic toxicity (reabsorption or accidental intravascular injection of the local anaesthetic), and also to permit the simultaneous use of neurostimulation.

Whether for a single injection or insertion of a catheter, the objective is to position the tip of the needle in proximity to C5 or C6. It is imperative to avoid injury to the phrenic nerve during insertion of the needle. For a continuous nerve block, once the tip of the needle is in place, the catheter is

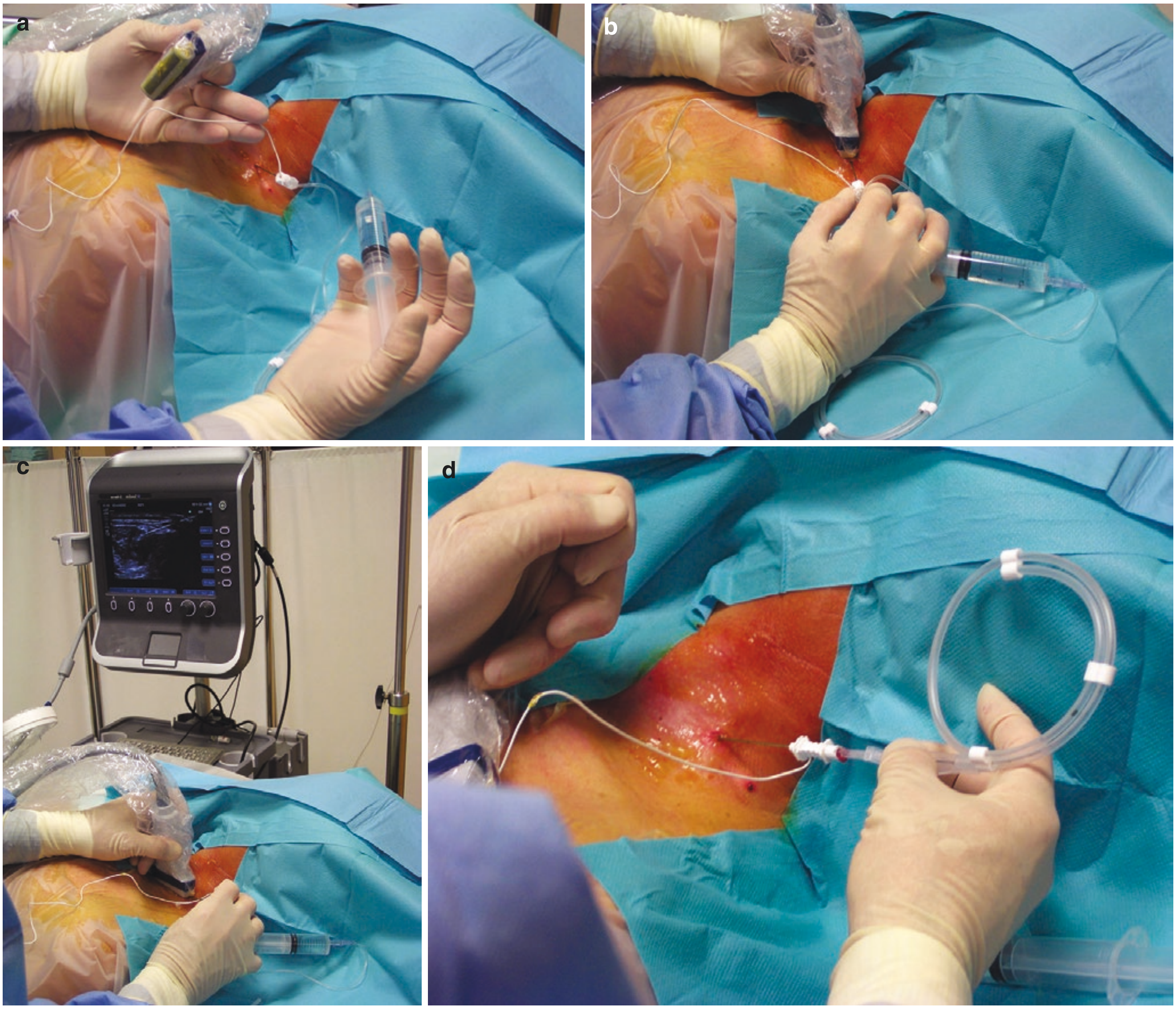


Fig. 5.41 Procedure for placement of an interscalene catheter. (**a**) Hold on the syringe. (**b**) Simultaneous needle insertion and injection with one hand. (**c**) Visualisation of needle position and spread of the local anaesthetic. (**d**) Introduction of catheter through the needle

Fig. 5.42 Removal of the catheter introducer sheath and then of the needle (**a**). Verification of proper spread of local anaesthetic through the catheter (**b**). Tunnelling of the catheter (**c**). Fixation and dressing (**d**, **e**)

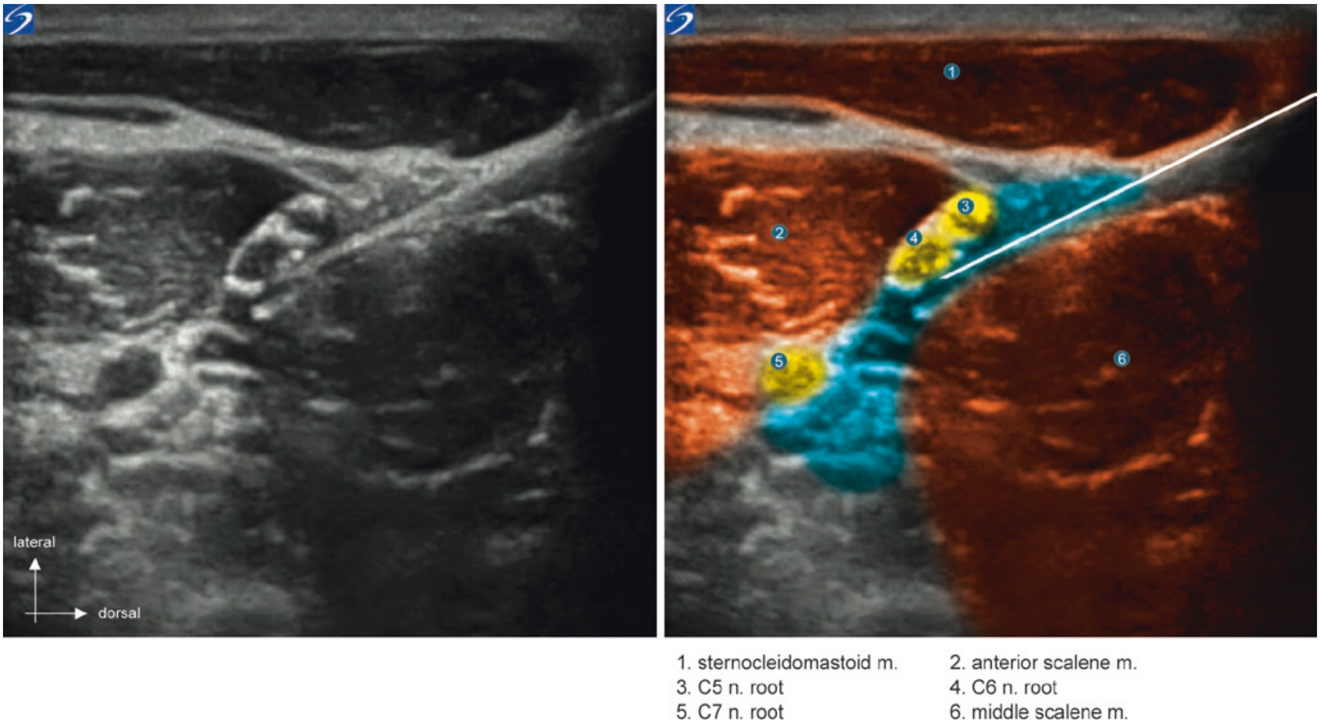


Fig. 5.43 Placement of an interscalene catheter. Injection trajectory not involving the middle scalene muscle

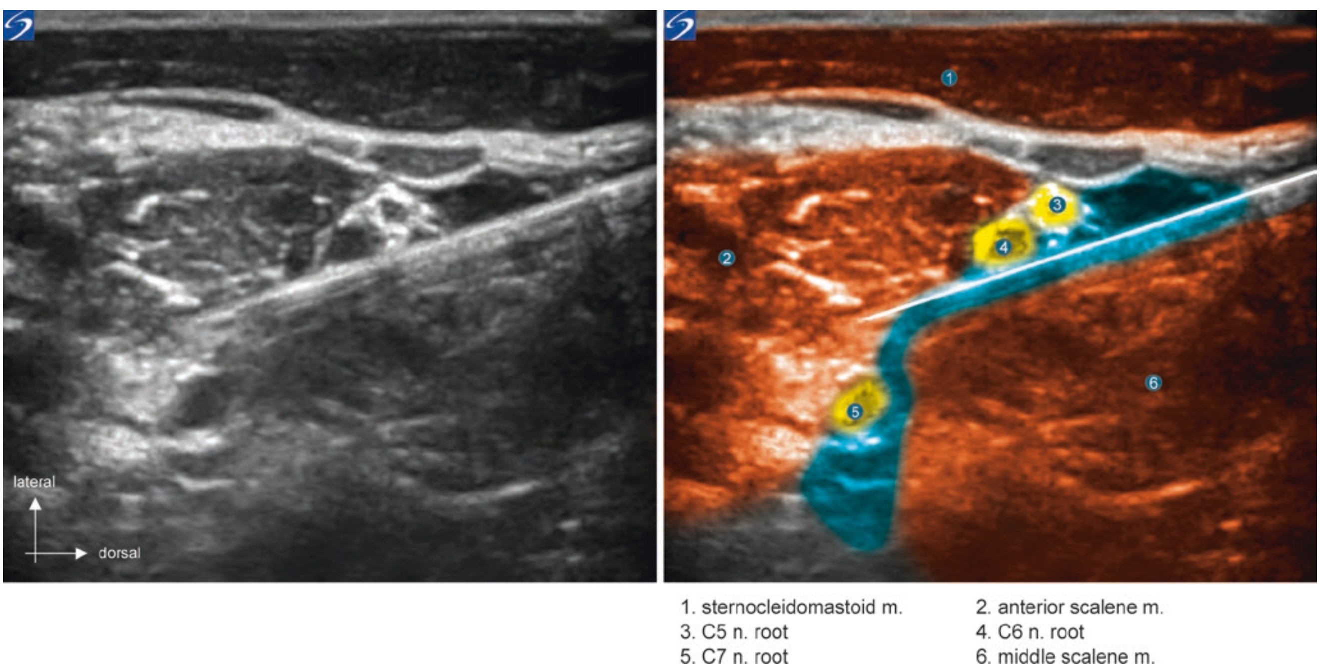
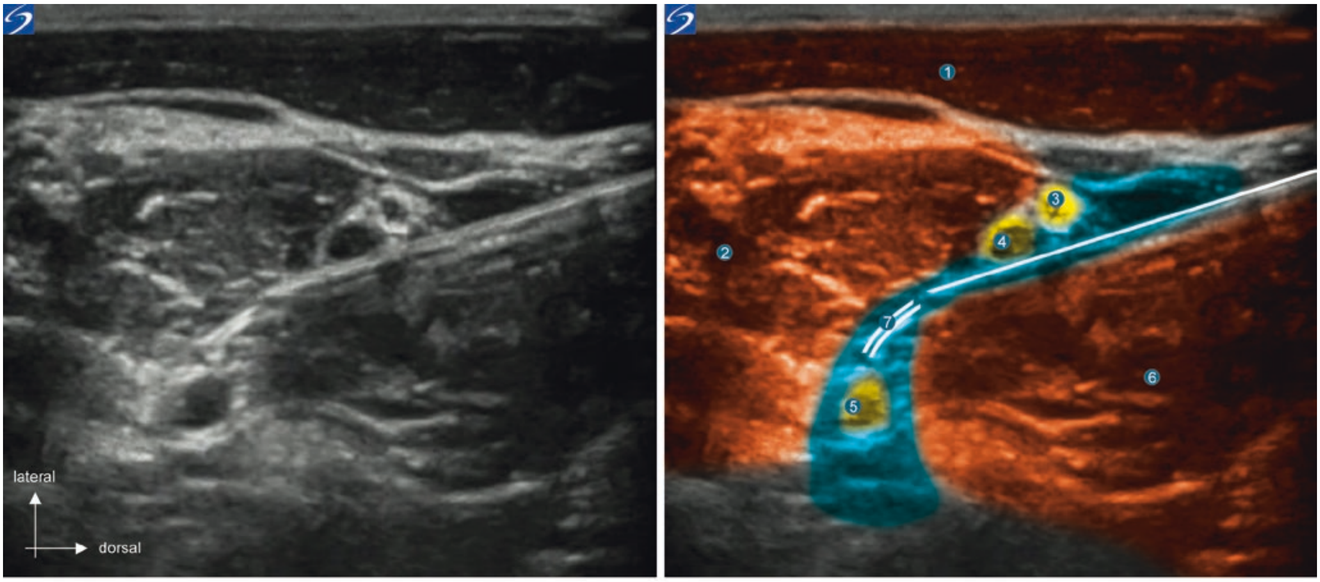
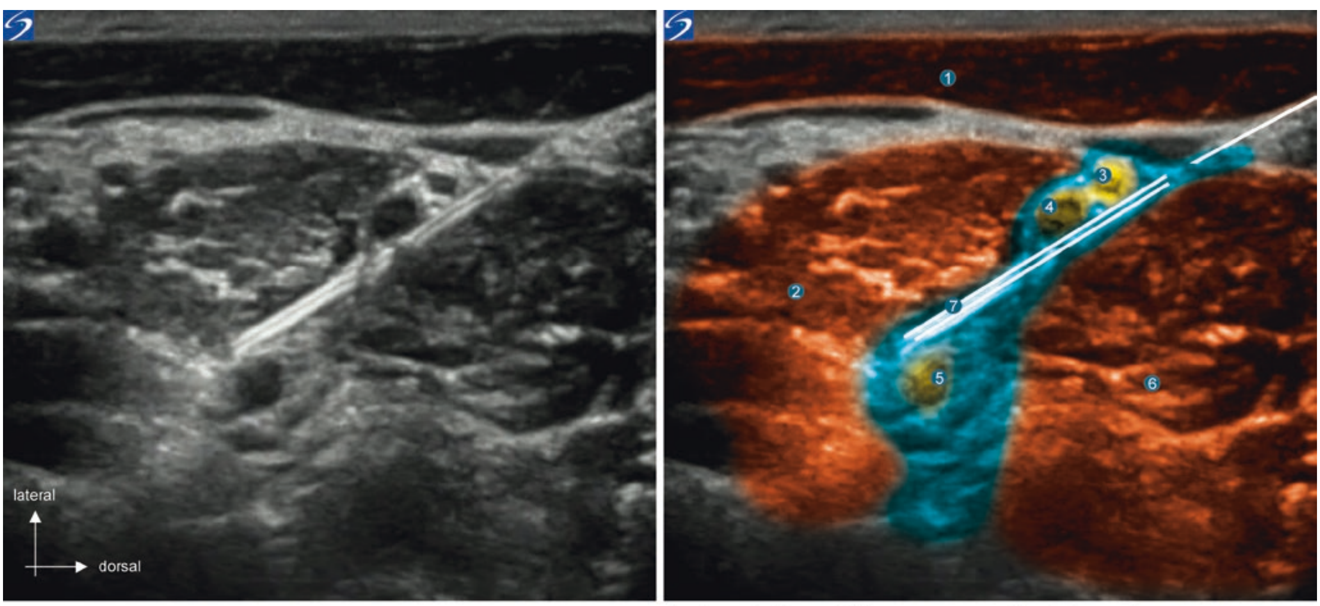


Fig. 5.44 Placement of an interscalene catheter. Bevel of needle placed superficial to the C7 nerve root



1. sternocleidomastoid m. 2. anterior scalene m.
3. C5 n. root 4. C6 n. root 5. C7 n. root
6. middle scalene m. 7. catheter

Fig. 5.45 Interscalene catheter "dropped" superficial to the C7 nerve root



1. sternocleidomastoid m. 2. anterior scalene m.
3. C5 n. root 4. C6 n. root 5. C7 n. root
6. middle scalene m. 7. catheter

Fig. 5.46 Interscalene catheter positioned superficial to the C7 nerve root after removal of needle

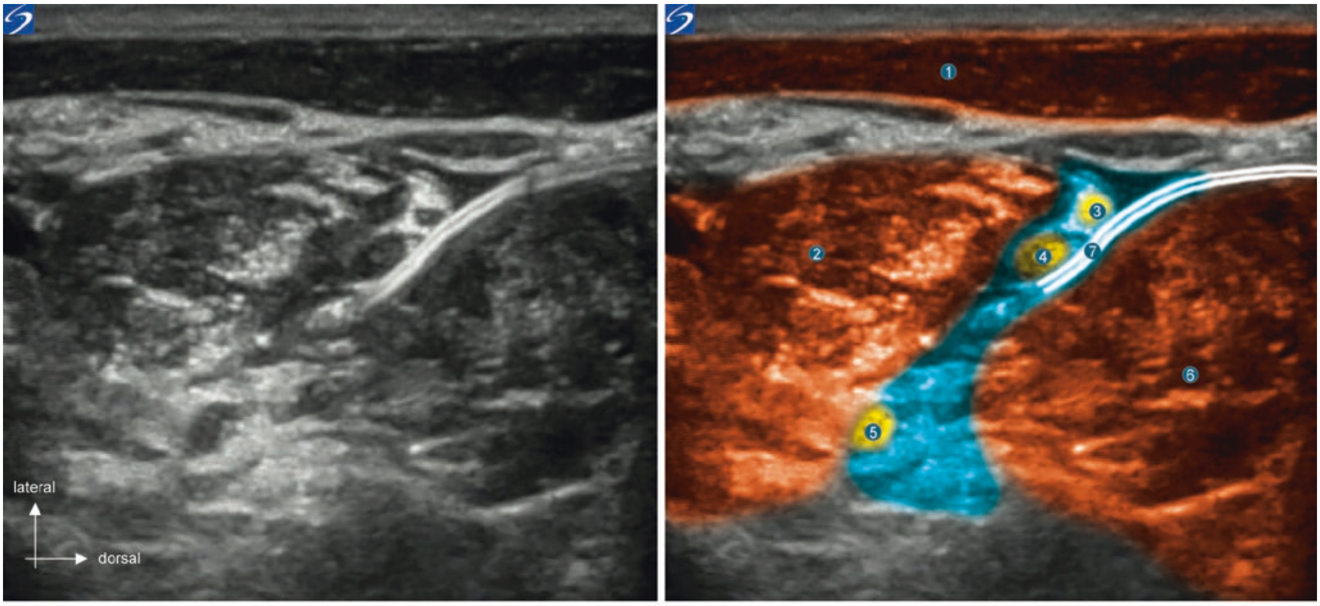


Fig. 5.47 Interscalene catheter positioned deep to the C6 nerve root. Optimal distribution of local anaesthetic around nerve roots C5, C6 and partly around C7

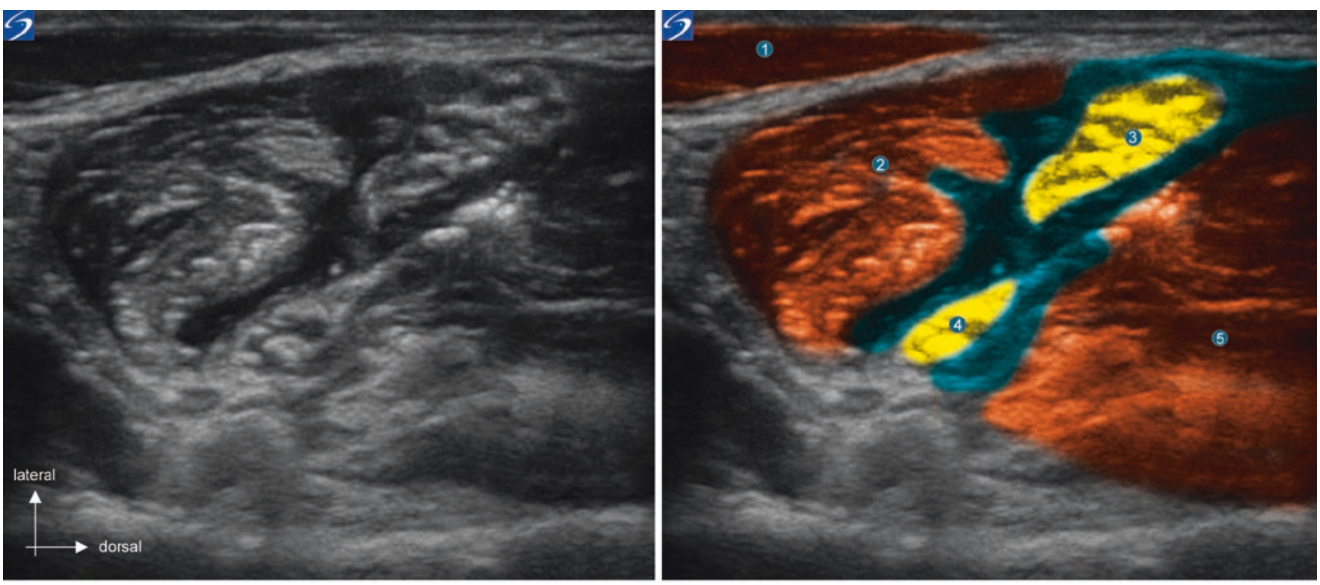


Fig. 5.48 Spread of the local anaesthetic in the interscalene area surrounding the superior (C5 + C6) and middle (C7) trunks

inserted into the needle in the same manner as an approach with neurostimulation only; in other words, it is advanced a few centimetres further in order to stabilise it.

Paediatrics
The shallow depth and small size of the anatomical structures should encourage use of caution. It is necessary to use a high frequency probe and to insist on optimising the ultrasound adjustment settings.

Supraclavicular Block (Fig. 5.49)

Traditional indications for supraclavicular block (SCB) are surgery on the upper end of the humerus with distal incision and elbow surgery. The supraclavicular approach does not require mobilisation of the upper limb, which makes it one of the techniques of choice in trauma cases, in the same category as infraclavicular block. It can be relatively easy in an obese subject where it can be a second-line choice for shoulder arthroscopy (the success rate is lower in an obese subject than in the non-obese patient, but the complication rates are identical [31]). It can replace an axillary or humeral BP approach for surgery of the hand and forearm in patients with a history of ipsilateral lymph node dissection [8]. Extension of anaesthesia occurs more distally than with an interscalene block, which makes supraclavicular block useful in surgery of the arm and elbow, whenever the incisions are made on the posterior aspect of the arm (for example, in fixation of humeral head or neck fracture) [32]. SCB is not indicated for hand surgery because blockade of the ulnar nerve is not constant [33]. Extension of analgesia to the axillary nerve makes it preferable to infraclavicular block for surgery requiring prolonged abduction of the arm (arthroscopy of the elbow), which is uncomfortable for the patient.

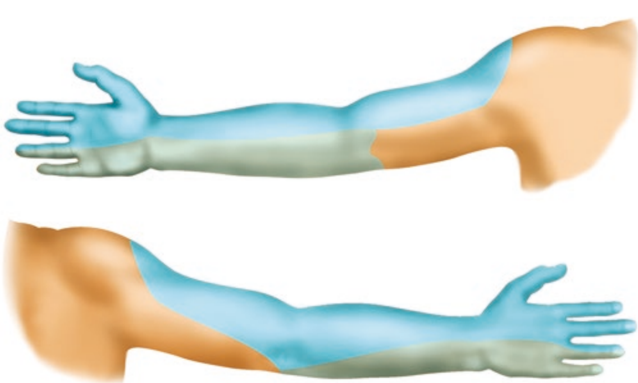


Fig. 5.49 Area of coverage of a supraclavicular block

It is in the supraclavicular level that the nerve structures of the brachial plexus (lateral, posterior and medial cords) are closest to each other. Induction of anaesthesia is obtained preferably in the area of the axillary, radial and musculocutaneous nerves. Due to the deeper position of the medial cord, median nerve block and in particular ulnar nerve block occurs later and regularly incomplete. With neurostimulation only, occurrence of a motor response in the area of the ulnar nerve is a warning sign because it corresponds to stimulation of the medial cord which is very close to the dome of the pleura. In case of mediocre or poor visibility, ultrasound guidance allows the needle to be directed superficial to the cords of the plexus in order to avoid the pleura [9].

In light of the proximity of the pleura and of the brachial plexus, this nerve block, with traditional neurostimulation, would carry the risk of pneumothorax. Many techniques have been described in order to decrease its incidence.

The incidence of pneumothorax ranges from 0.36% with Kulenkampff's traditional technique [34] to 6% [35]. The risk was higher in thin, slender subjects, and more frequent in the right lung rather than the left [6]. Since signs of pneumothorax are often minimal and of late onset, supraclavicular block was contraindicated in ambulatory surgery [36]. To avoid injury to the lung tissue, the proposed techniques involve assessment of the depth of the plexus and of the pleura, the length of the needle, the landmarks at the injection site and the direction of injection, and other aids in locating the target [37]. The most recent technique is ultrasound, which readily enables to recognise and avoid "susceptible" structures near the plexus, namely blood vessels, the pleura and the lung.

Estimating the depth of the brachial plexus varies depending on technique. The relative complexity of these methods of assessment [38] makes them unsuitable for everyday use.

The majority of historical techniques for supraclavicular approach to the brachial plexus use the subclavian artery as an essential landmark [39–43]. However, its location sometimes is clinically difficult to determine but greatly facilitated by use of Doppler method or with ultrasound. Easier to use surface landmarks have been proposed: middle of the clavicle [44], the scalene muscle area [45], the external jugular vein and trapezius muscle [42], and the heads of the sternocleidomastoid muscle [46].

Traditionally, the direction of injection was caudal, slightly medial and posterior [41], and is towards the inner aspect of the first rib towards the dome of the pleura. According to Winnie [43], the direction of the needle, in particular, should not be posterior nor medial but should remain parallel to the lateral border of the scalene muscles. Since these muscles insert on the first rib, the needle will necessarily pass on the outside. In order to avoid the pleura, the axis of injection can be lateral [42–45], introducing the notion of tangential approach to the plexus.

In these approaches, for a better definition, the axis of injection passes through a fixed point such as the subclavian artery [45], the earlobe [42] or the middle of the clavicle [44]. A totally different concept of injection has been proposed with the technique of a “plumb line” [46] where the plexus is approached in a strict anteroposterior sagittal plane, above the clavicle, outside of the insertion of the sternocleidomastoid muscle. This approach does not protect from pneumothorax any more than the other techniques.

All these techniques which attempt to avoid hazardous structures are no longer used since the advent of ultrasound. Visualisation of the pleura enables to remain at a distance from it, under reservation of seeing the tip of the needle. Use of ultrasound in fact does not completely eliminate the risk of pneumothorax [47].

Type of probe: linear, 6–13 MHz.
Axis of probe: transversal/short axis (Fig. 5.50).
Configuration: nerves in the short axis, needle in plane.
Study depth: 2–3 cm.
Neurostimulation: enables further identification of the nerves visualised and can limit, by determination of an MIS >0.3 mA (0.1 ms), the risk of accidental intrafascicular injection. Furthermore, it can supplement locating nerves when conditions of visibility are unfavourable.
The high prevalence of anaesthetic failure in the territories C8-T1 during supraclavicular nerve block is related to the anatomical isolation (aponeurotic interpositions, independent sheath) of C8-T1 components from the remainder of the plexus at this level. Neurostimulation can be useful in positioning of the injection in contact with these nerves in order to anaesthetise them correctly and thus restore supraclavicular nerve block as being reproducible, effective on the entire brachial plexus.
Needle: 50–80 mm isolated, 22G.
Utility of Doppler: subclavian vessels, transverse cervical vessels, dorsal artery of the scapula, costocervical trunk.

Fig. 5.50 Supraclavicular block. Position of the probe parallel to the clavicle, injection in-plane, lateral approach

Echoanatomy
The brachial plexus, at this level, is cephalic and lateral in relation to the subclavian artery, which generally is in close contact with the first rib and the pleura (Figs. 5.51 and 5.52). Very frequently, the plexus is crossed by the dorsal artery of the scapula (which should be sought), a branch of the subclavian artery or of the thyrocervical trunk, whose diameter can be relatively large, and which generally continues between the trunks of the plexus (Figs. 5.53 and 5.54). Generally, the latter is “tied” by the transverse artery of the neck, also a branch of the thyrocervical trunk in cephalic position. It is sometimes also possible to locate the costocervical trunk which arises from the posterior aspect of the subclavian artery and which can be in close contact with the brachial plexus in its medial part. These arteries, most of the time together with the veins, can be located with Doppler ultrasound to avoid accidentally injuring them (Fig. 5.55). Note that cases of accidental injection of a blood vessel have been reported in spite of an in-plane injection [48, 49]. In the brachial plexus, it can be observed that the nerve roots of C8-T1, which comprise the lower trunk, are located more in proximity to the subclavian artery, generally in the deep layer, against the first rib.

Pathways of Approach

As with the interscalene block, the supraclavicular block of the brachial plexus should be considered differently to the technique with neurostimulation. It is possible primarily to differentiate the lateral approach and the medial approach. Both involve the trajectory of the needle in the direction both of blood vessels and of the lung. Since the latter structures

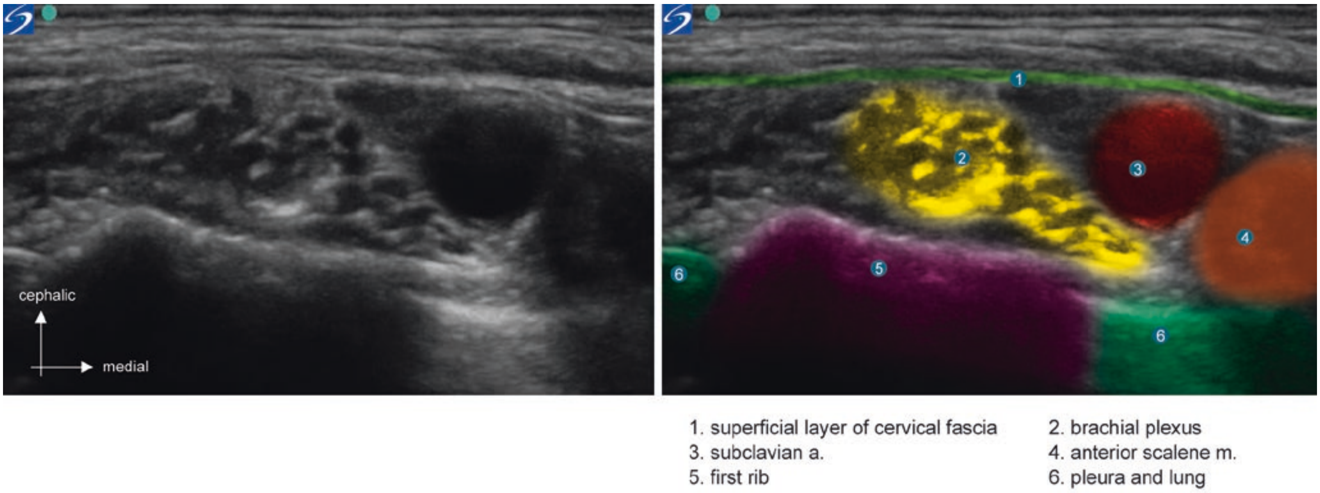


Fig. 5.51 Ultrasound section at the supraclavicular level

can be readily identified with ultrasound, they are avoided by maintaining careful strict visual control of the needle.

For each of the two approaches, the probe is positioned in the supraclavicular fossa, parallel to and immediately above the clavicle. Use of a small probe is comfortable and sometimes necessary in patients with a small supraclavicular fossa (children). The medial approach is often more useful in patients with a deep supraclavicular fossa or a protruding trapezius muscle which hinders the trajectory of the needle from the lateral end of the probe.

Lateral Approach

Nerve Localisation

The first phase consists of confirming the exact nature of the structures visualised by scanning between the interscalene and supraclavicular regions. Thus, it is possible to see, during descending scanning, that the roots C5, C6 and C7 progressively become superficial in the interscalene approach, comprise the upper and middle trunks, form anterior and posterior divisions and give rise to their first collaterals and are joined by C8 and T1, lastly, to regroup in a cranial lateral position in relation to the subclavian artery (Fig. 5.51). This "elevator" technique enables to define the outline of the plexus.

Needle Insertion

The needle is inserted, after local anaesthesia infiltration of the skin, at the lateral end of the probe (Fig. 5.50). It should be inserted and guided in the ultrasound plane to remain visible constantly along its length. In the event that vascular structures have been visualised in the plexus, they are avoided by directing the ultrasound plane and thus the pathway of the needle, either to no longer see them and consequently to not cross them, or on the contrary, to visualise them well and thus be able to control them.

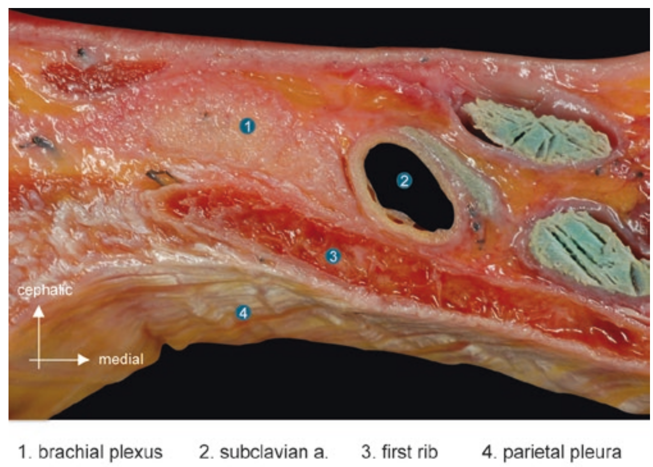


Fig. 5.52 Anatomical relations of the brachial plexus with blood vessels and pleura in the supraclavicular area. (Iconography: Admir Hadzic)

Injection

The elements/components of the plexus at this level are all stuck together and it is almost impossible to differentiate a small nerve from a large bundle. Therefore, it is entirely possible, by advancing the needle, in this "mass" of nerve structures, to involuntarily perform an intraneural puncture followed by intraneural injection, even though it is possible for

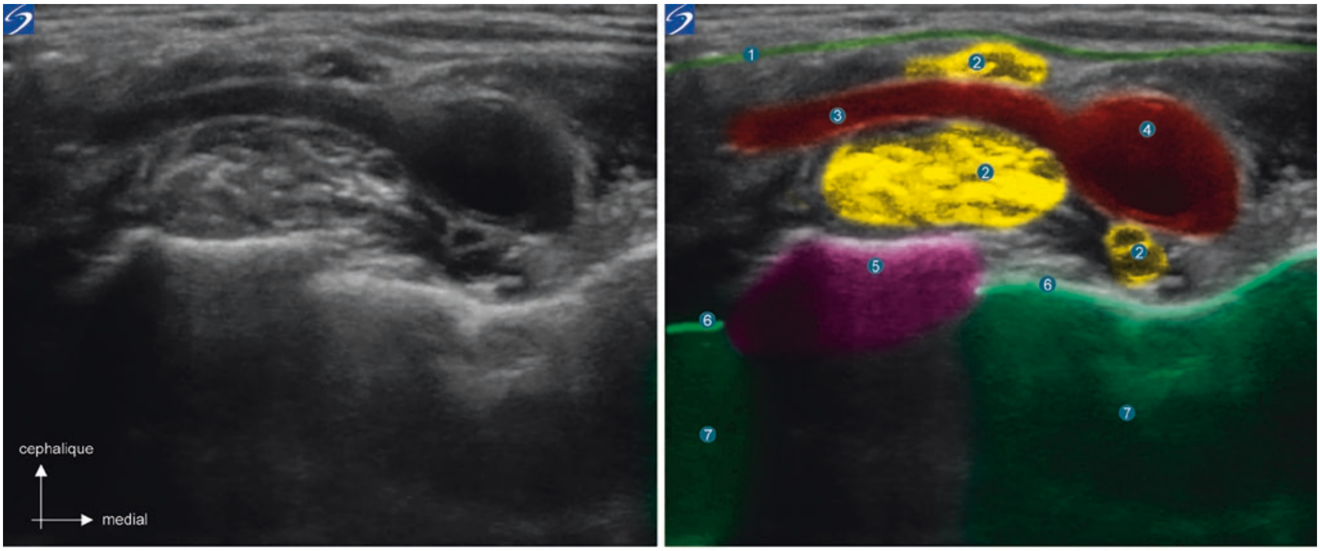


Fig. 5.53 Dorsal scapular artery crossing the brachial plexus at the supraclavicular level

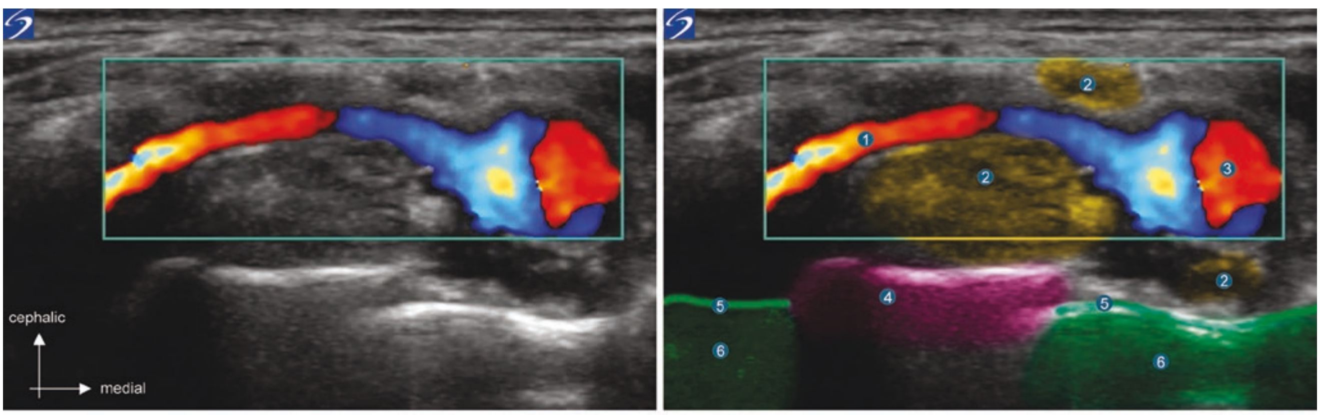


Fig. 5.54 Dorsal scapular artery at the supraclavicular level. Confirmation by Doppler ultrasound

the clinician to think that the needle is located between the nerves. Consequently, **the author strongly suggests not** to place the needle in the middle of the plexus and to inject right into it in this manner, contrary to what may sometimes be suggested by other commentators. Thus, the safest approach consists of starting the injection on the surface of the plexus (Fig. 5.56) and possibly, depending on spread of the local anaesthetic, to redirect it in order to optimise its distribution in contact with the nerve branches. If the objective is to perform anaesthesia on the entire brachial plexus (including C8-T1), the needle should be cautiously redirected towards the roots C8 and T1 which lie in the deep layer of the plexus, generally in the confines of the superficial plane of the first rib and of the subclavian artery (Fig. 5.57). This procedure is done by avoiding the plexus at its lateral edge, taking care to avoid any risk to the adjacent pleura and lung. It is often possible to make this procedure safe by positioning the probe in a manner so that the plexus is placed on the first rib and so that the latter serves as a “barrier” to the pleura and to the lung (Fig. 5.58).

Fig. 5.55 Dissection of the brachial plexus in the supraclavicular level. Anatomical relations with blood vessels. (Dissection: Bertrand Fabre)

Medial Approach

The probe is positioned in the supraclavicular fossa, generally slightly more laterally than the lateral approach. This approach can be useful when the patient has a trapezius muscle that is especially protruding and/or when the supraclavicular fossa is deeper.

Nerve Localisation

Just as with the lateral approach, it is necessary first to determine the exact position of the plexus and of its general outline. This step makes it possible to position the probe in “strategically”: the puncture point should enable the trajectory of the needle to lie between the subclavian artery and the plexus, which will facilitate injection of the local anaesthetic more in contact from C8 to T1, and thus anaesthetise the corresponding areas. This technique is similar to supraclavicular block by inter-sternocleidomastoid approach although, with ultrasound guidance, the injection point generally is lateral compared to the clavicular head of the sternocleidomastoid muscle.

Needle Insertion

The needle is inserted after local anaesthesia infiltration of the skin, at the medial end of the probe (Fig. 5.59). It should

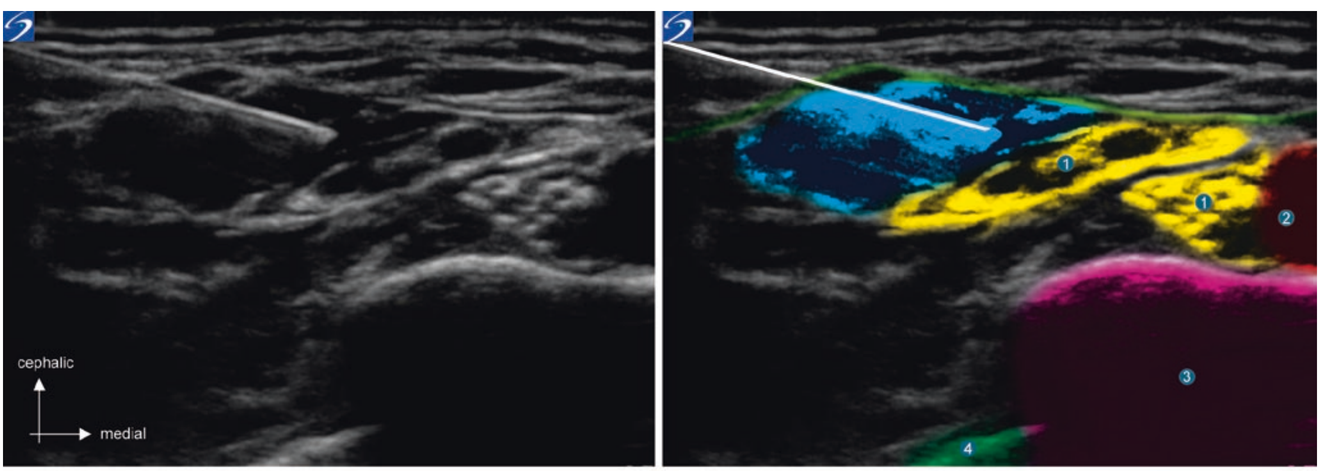


Fig. 5.56 Supraclavicular block. Injection of local anaesthetic superficial to the plexus

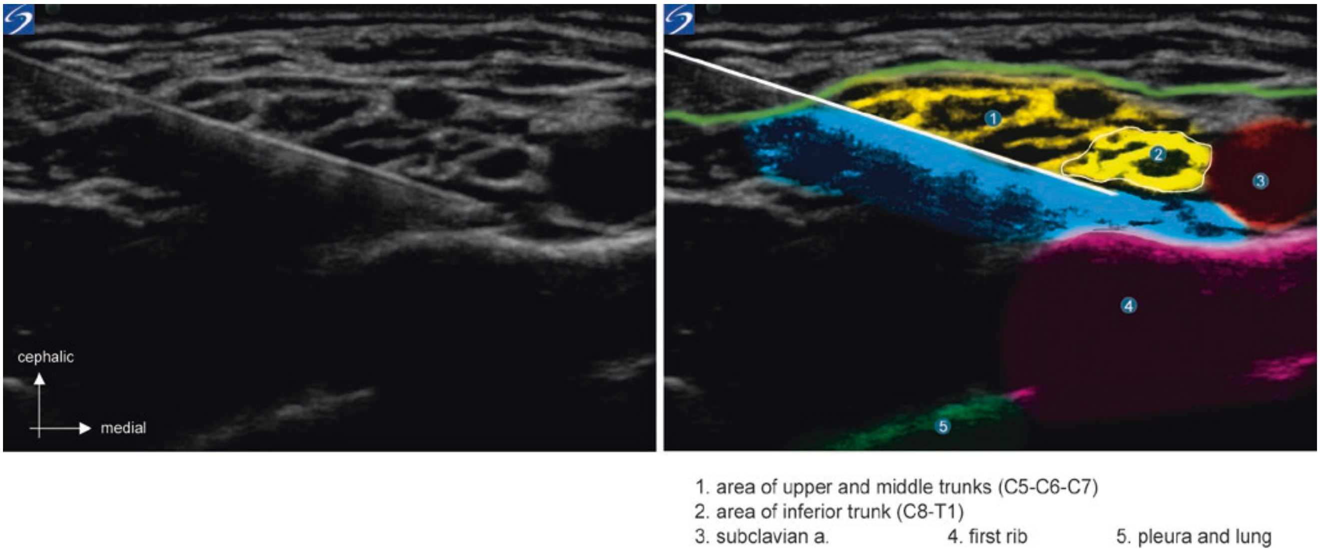


Fig. 5.57 Supraclavicular block. Needle in contact with nerve roots C8-T1

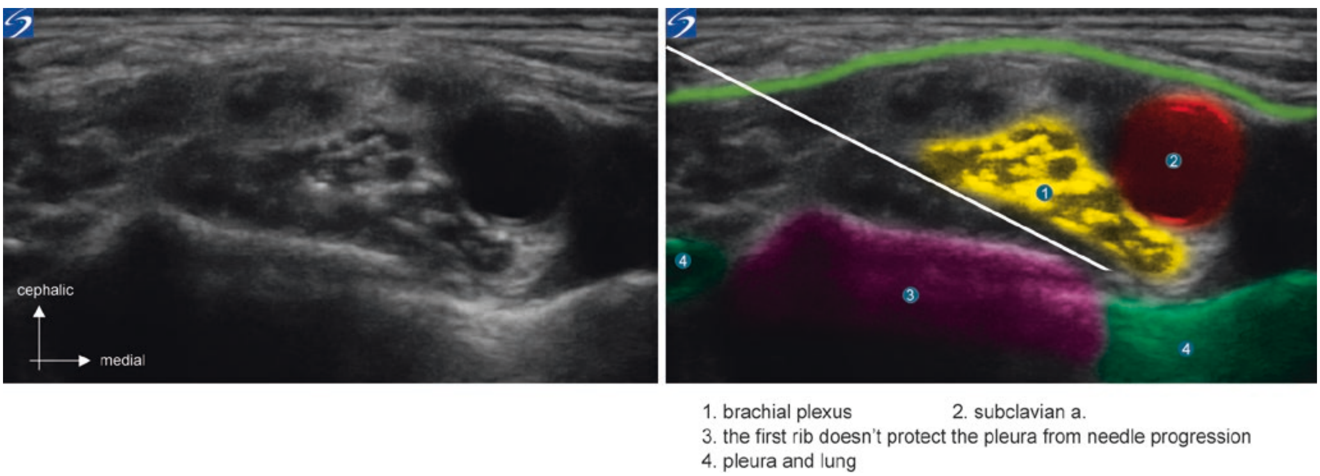


Fig. 5.58 Supraclavicular block. Needle in contact with nerve roots C8-T1. Safe procedure positioning the probe such that the plexus lies on the first rib acting as a "shield" for the pleura and lung

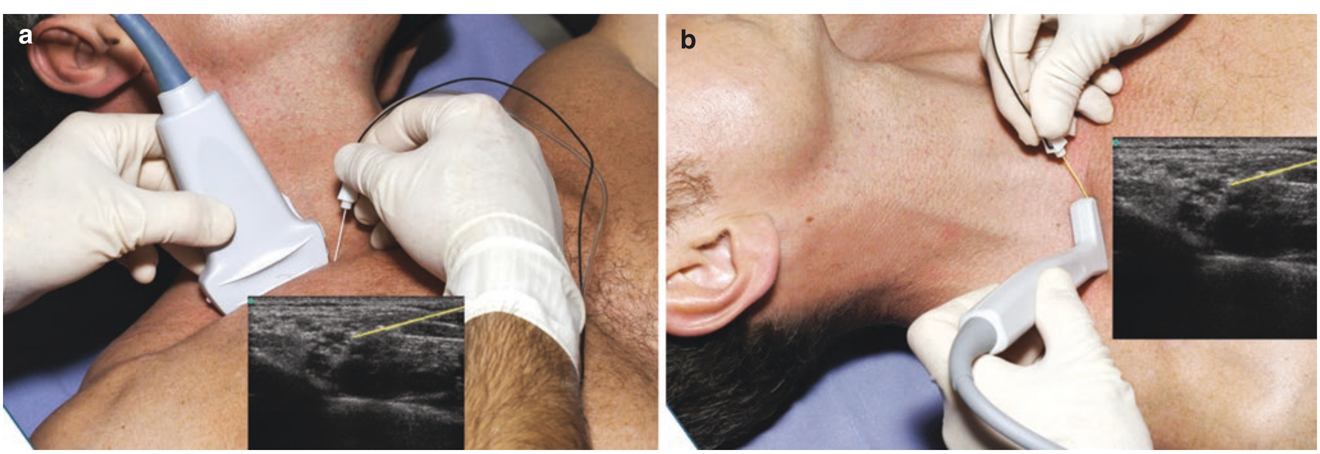


Fig. 5.59 Supraclavicular block: medial approach with two different probes (as this is a demonstration, the probe has not been covered with a dedicated cover that would be used during the actual performance of the block)

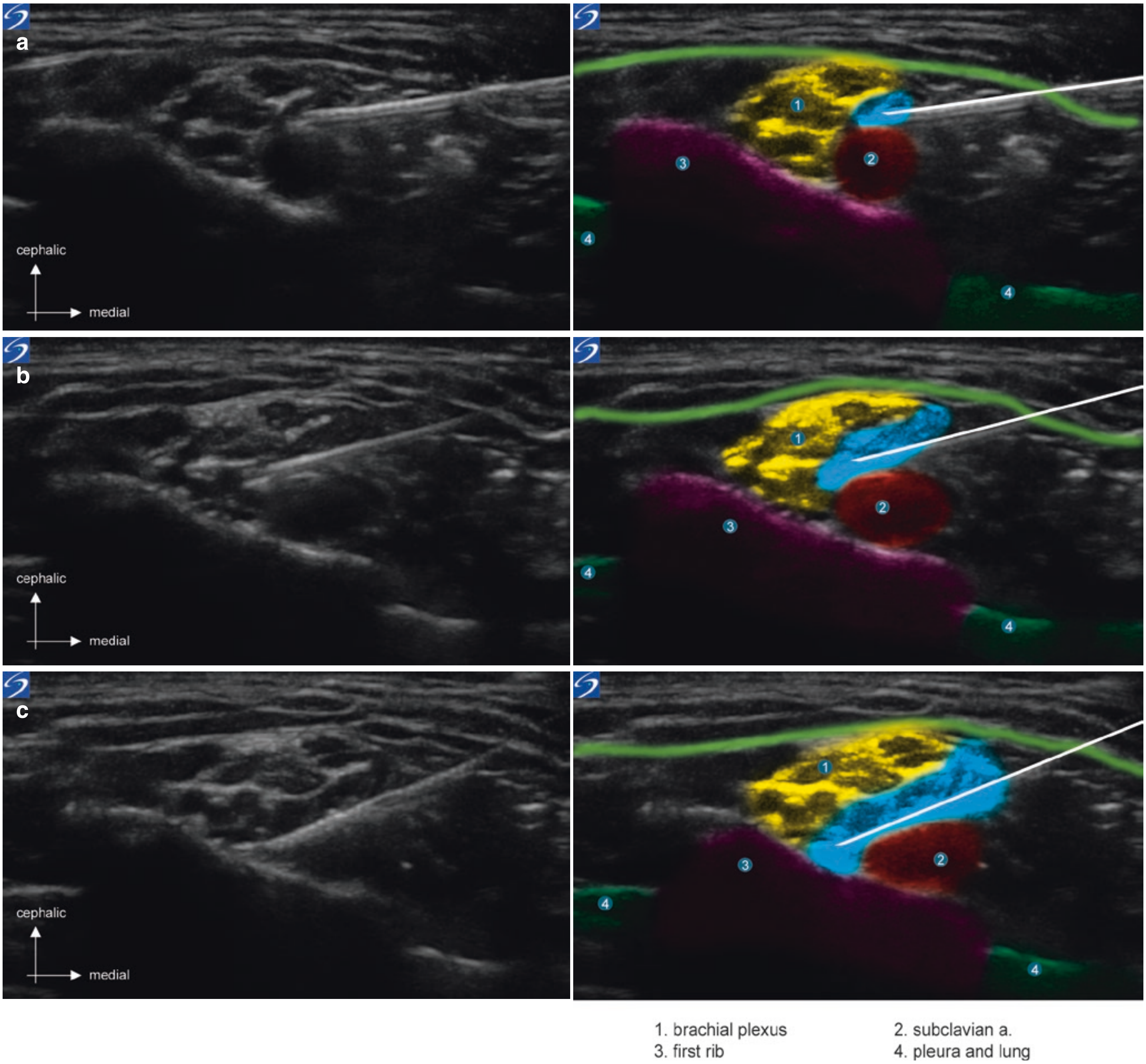


Fig. 5.60 Supraclavicular block: medial approach. Delicate progression of the needle between medial border of the plexus and subclavian artery

be inserted and guided in the ultrasound plane in order to remain visible along its entire length (Fig. 5.60).

Injection

The injection is administered in contact with the elements/components of the plexus, with the possibility of redirecting the needle and the spread of the local anaesthetic during the procedure, if necessary. This approach can facilitate injection of the local anaesthetic in contact with the components C8 and T1 (inferior trunk) by carefully sliding the needle between the subclavian artery and the medial limit of the plexus, and by avoiding crossing the remainder of the plexus to reach them (Fig. 5.60c).

Paediatrics

The close proximity between the brachial plexus and the "susceptible" anatomical structures, i.e. the pleura, subclavian vessels and their collateral branches, is such so that this block is rarely used in paediatric practice with neurostimulation alone. The visual control dimension provided by ultrasound can make it possible to enhance the place given to this approach in the arsenal of peripheral nerve blocks in children.

Infraclavicular Block (Fig. 5.61)

Indications

Indications for infraclavicular block (ICB) are upper limb surgeries, from the proximal third of the humerus to the hand. Cases of trauma to the upper limb is the indication of choice because of the advantage of not moving the arm for performing the block, whatever the technique used.

There are many traditional pathways of approach. Their classification will depend on their direction in relation to the plexus, that is, their position in the upper part of the thorax:

– The perpendicular pathway (Kilka [50, 51] and subcoracoid approach [52]) or tangential to the brachial plexus (Raj [53], Sims [54] and Borgeat [55] pathways)
– The very medial pathways (Kilka) or extra-thoracic (subcoracoid)

In the medical literature, the risk of pneumothorax is low and these approaches are indicated for insertion of an indwelling catheter. The area of insertion is hairless, relatively immobile and clean, with very low risk of infection. Transmuscular injection, crossing the pectoralis major muscle, seems to be the psychological limit of subclavicular approaches. These blocks are deep and consequently are contraindicated in the presence of coagulation disorders because of difficulty in compressing a blood vessel which has been injured by direct needle puncture.

Infraclavicular nerve block is indicated primarily for trauma surgery of the arm, elbow or forearm. For insertion of catheters, a tangential technique will be chosen. With neurostimulation only, multi-stimulation makes it possible to decrease the total volume of local anaesthetic, to increase the success rate and accelerate the time to onset of the nerve block [6]. Injection of a local anaesthetic around the different cords of the plexus has this advantage. The use of ultrasound is an essential too; to guide the injection around the artery, on the three cords of the brachial plexus. In fact, by observing spontaneous spread of the local anaesthetic, we note that the latter is not distributed systematically in contact with the three components, including when the injection is administered deep to the axillary artery in immediate proximity to the posterior cord. However, it is here that is advisable to inject a local anaesthetic.

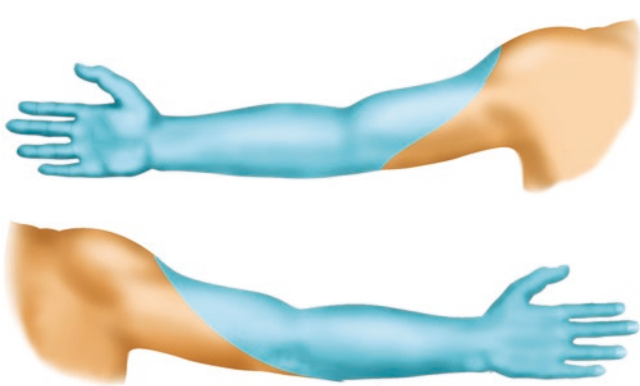


Fig. 5.61 Area of coverage of the infraclavicular block

The indication for conduct of an infraclavicular block on the side of an arteriovenous fistula should be weighed conscientiously in light of the impossibility of exerting pressure in case of a haematoma. In the event that another anaesthetic technique is not feasible, it is absolutely necessary to use rigorous ultrasound-guided technique.

Type of probe: linear, 5–10 or 6–13 MHz.
Axis of probe: parasagittal (Fig. 5.62).
Configuration: nerves in the short axis, needle in plane.
Studied depth: 2–6 cm.
Neurostimulation: enables further identification of the nerves visualised and can limit, by determination of an MIS >0.3 mA (0.1 ms), the risk of accidental intrafascicular injection. Furthermore, it can supplement locating nerves when conditions of visibility are unfavourable.
Needle: 80 mm isolated, 22 G.
Utility of Doppler ultrasound: primarily axillary vessels, thoracoacromial, upper and lateral thoracic or cephalic vein.

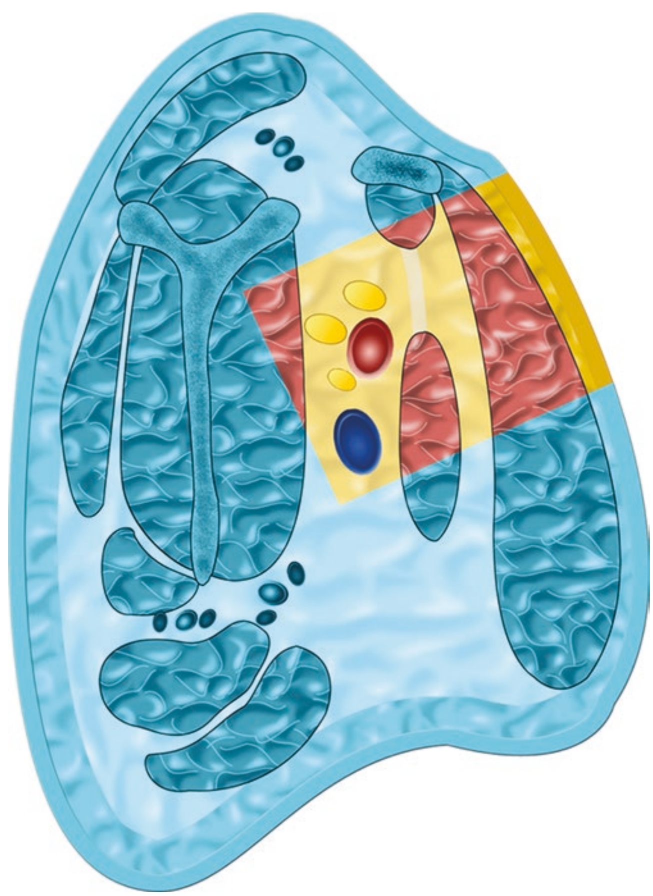


Fig. 5.62 Parasagittal section of the axillary fossa with materialisation of the ultrasound beam

Echoanatomy

As it enters the axillary region, the brachial plexus is in lateral position in relation to the blood vessels. All of this neurovascular bundle located deep to the pectoralis major and pectoralis minor muscles, continues in an oblique inferior pathway, running laterally and dorsally, and continues tangentially with the rib cage and then distances itself from it to enter the medial aspect of the arm. At the start of their journey through the axillary region, the lateral, medial and posterior cords are initially stuck together (Figs. 5.63 and 5.64), but they then rearrange around the blood vessels to position themselves laterally, medially and posteriorly in relation to the artery (Fig. 5.65). The terminal branches of the brachial plexus then arise opposite the shoulder joint. Major variations in position of the bundles around the blood vessels may possibly exist. Moayeri et al. [56] have showed that the relations of the nerve structures with respect to the axillary artery are changed as their "distal end" is approached, but that they also vary in patients in a given sectional plane (Fig. 5.66).

An infraclavicular block is qualified as deep also because of the difficulty regularly encountered in correctly visualising the different bundles. Perlas et al. identified them precisely in only 27% of cases [57].

Approach

The principal technique is an approach in the ultrasound plane, by cranial-caudal direction. The probe is positioned according to a parasagittal infraclavicular axis, its cranial end is placed just medially to the coracoid process. The ideal cutaneous puncture site lies between the clavicle and the cranial end of the probe, and once the cutaneous plane has been crossed, it makes it possible to direct it in contact with the three cords by simple redirection during the injection.

Parasagittal Probe, Needle in Plane

Nerve Localisation

Deep to the pectoralis major and minor muscles, the lateral, medial and posterior cords are organised around the axillary artery. By ultrasound scanning, it is necessary to determine their relative positions in the different levels of the infraclavicular area. Consideration must be given to the deep position of the plexus, the inability to apply pressure in the case of inadvertent vascular puncture, the existence and position of the thoracoacromial blood vessels and of the cephalic vein in particular. These are all important parameters in the choice of the injection site for an infraclavicular block (Fig. 5.67). The probe is gen-

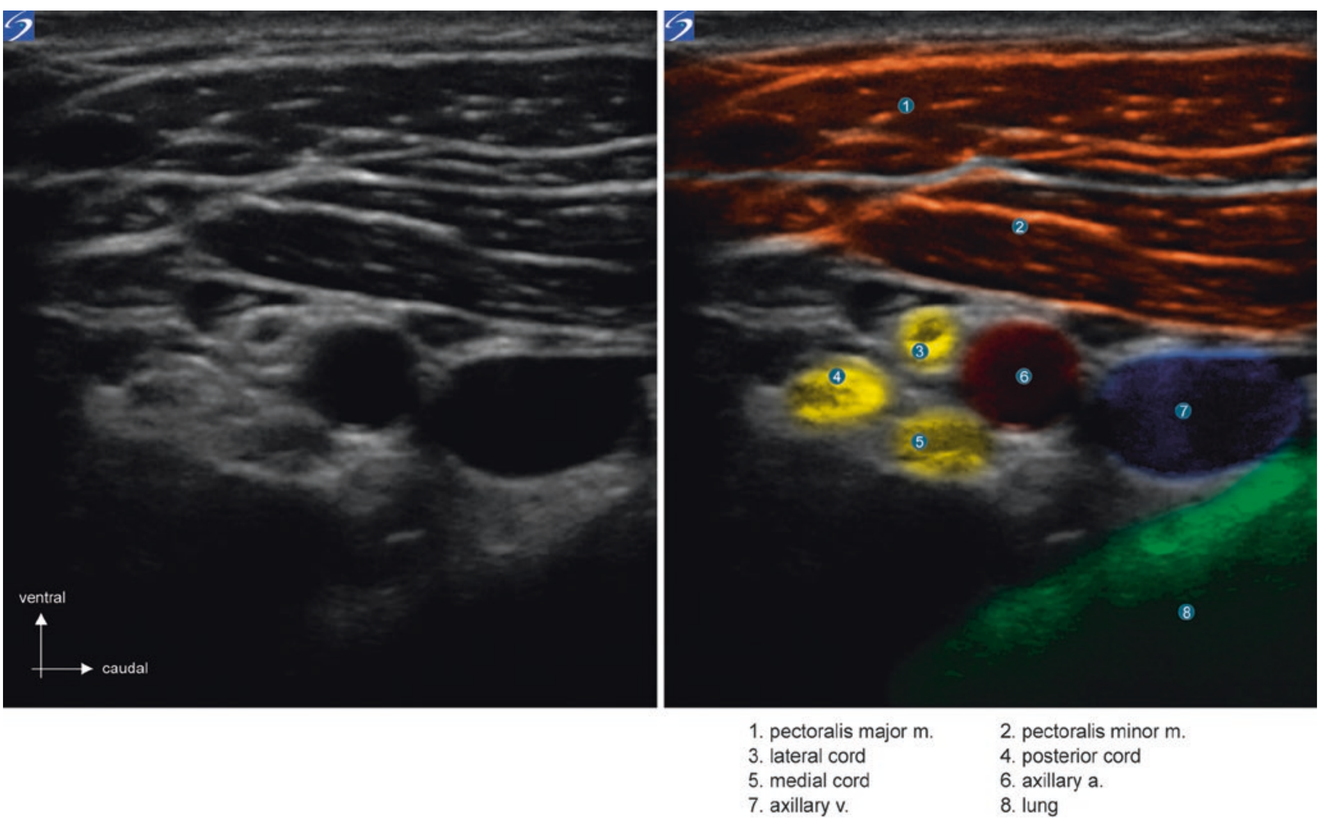
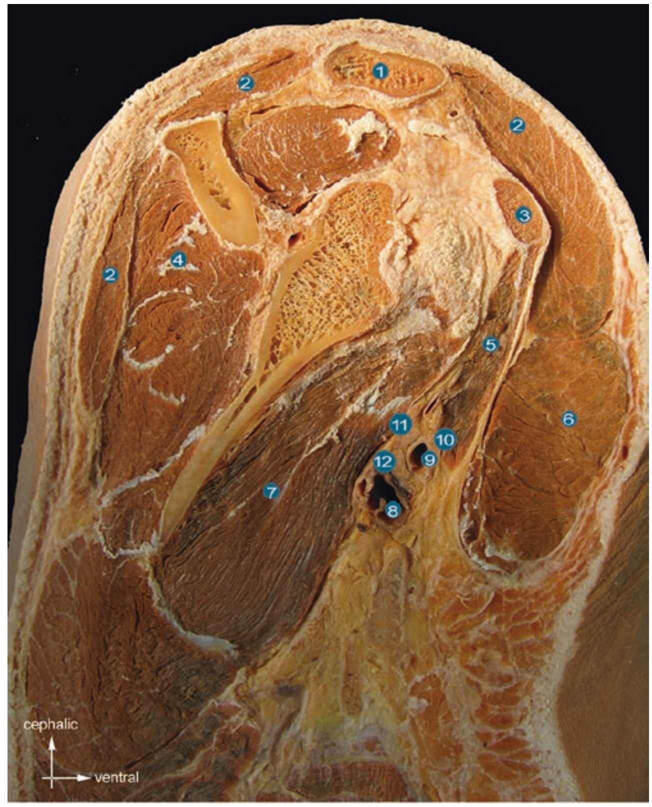


Fig. 5.63 Sonoanatomical section at the infraclavicular level

1. deltoid m.
2. supraspinatus m.
3. infraspinatus m.
4. subscapularis m.
5. subclavius m.
6. pectoralis major m.
7. pectoralis minor m.
8. axillary v.
9. axillary a.
10. medial cord
11. posterior cord
12. lateral cord

Fig. 5.64 Parasagittal section of the brachial plexus, axillary fossa



1. clavicle
2. deltoid m.
3. coracoid process
4. infraspinatus m.
5. pectoralis minor m.
6. pectoralis major m.
7. subscapularis m.
8. axillary a.
9. axillary v.
10. lateral cord
11. posterior cord
12. medial cord

Fig. 5.65 Parasagittal section of the brachial plexus cutting through the coracoid process

erally positioned just medially to the coracoid process (Figs. 5.62 and 5.68). Its axis is not systematically strictly parasagittal and may sometimes be directed more or less medially depending on if it is desired "to cut" the neurovascular axis perpendicularly. The pectoralis muscles, the axillary artery and vein, their efferent and afferent vessels, and the nerve structures are visualised (the cords and collateral branches of the brachial plexus) and, more caudally, the lung, pleura (Fig. 5.69), as well as most of the time, the second rib.

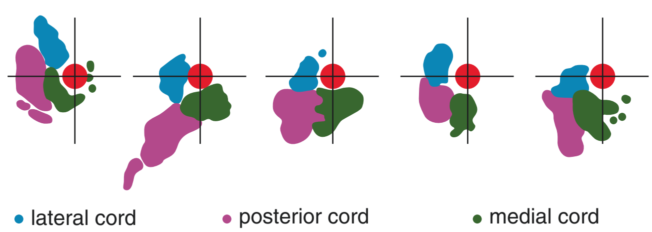


Fig. 5.66 Distribution of the cords of the brachial plexus around the axillary artery. (From [56])

Needle Insertion

The ideal cutaneous puncture point, at the cephalic end of the probe, should enable the three cords of the plexus to be reached by means of successive needle redirections. After local anaesthesia infiltration of the skin, the needle crosses successively the pectoralis major and the pectoralis minor muscles. It is only once the deep aponeurosis of the pectoralis minor muscle has been crossed that neurostimulation is started, thus making it possible to avoid patient discomfort related to stimulating the pectoral muscles. The high angulation of the needle necessary to reach

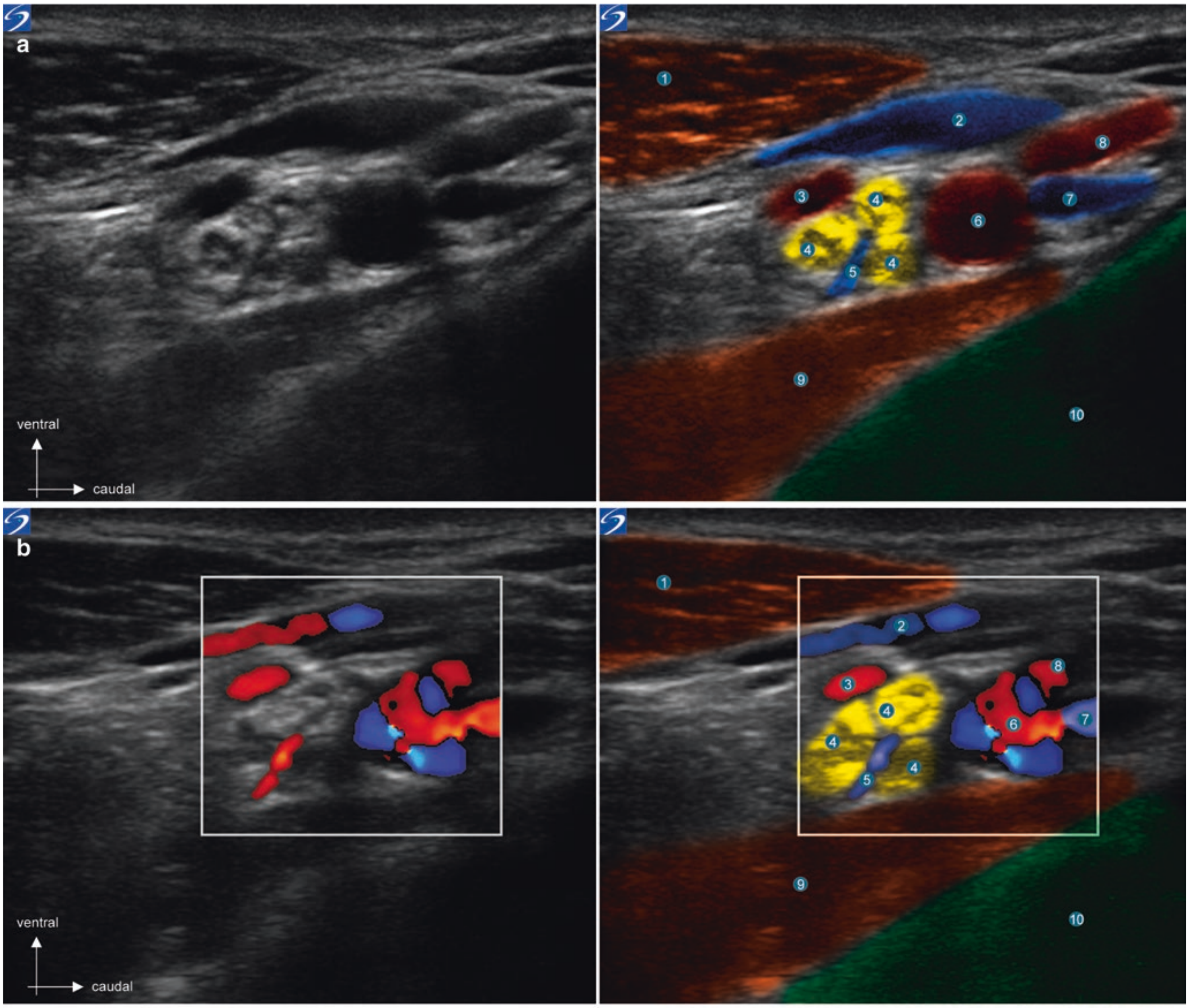
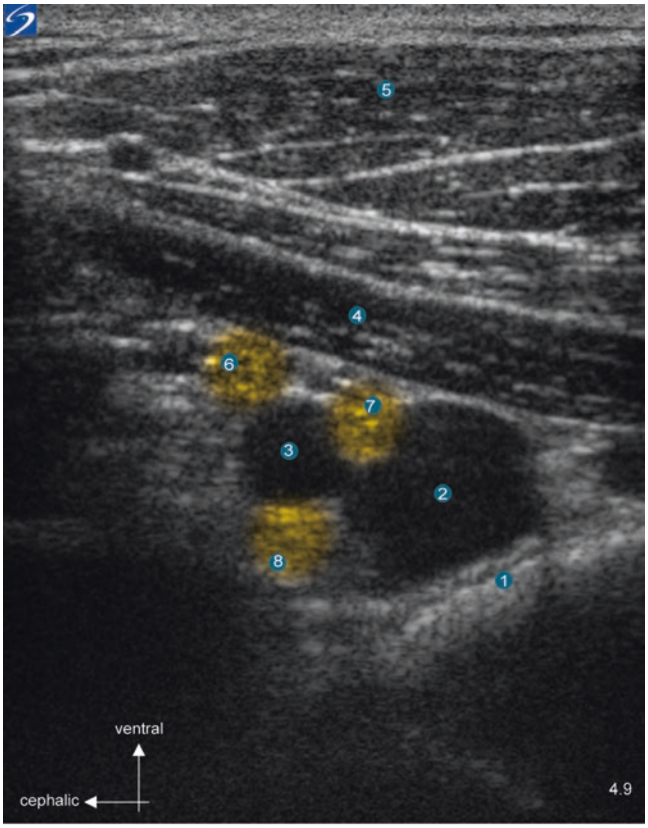


Fig. 5.67 B mode (**a**) ultrasound and colour Doppler (**b**) ultrasound section of the infraclavicular region showing the many vascular structures that can be found in it

Fig. 5.68 Ultrasound-guided infraclavicular block: position of the probe. Needle inserted in-plane



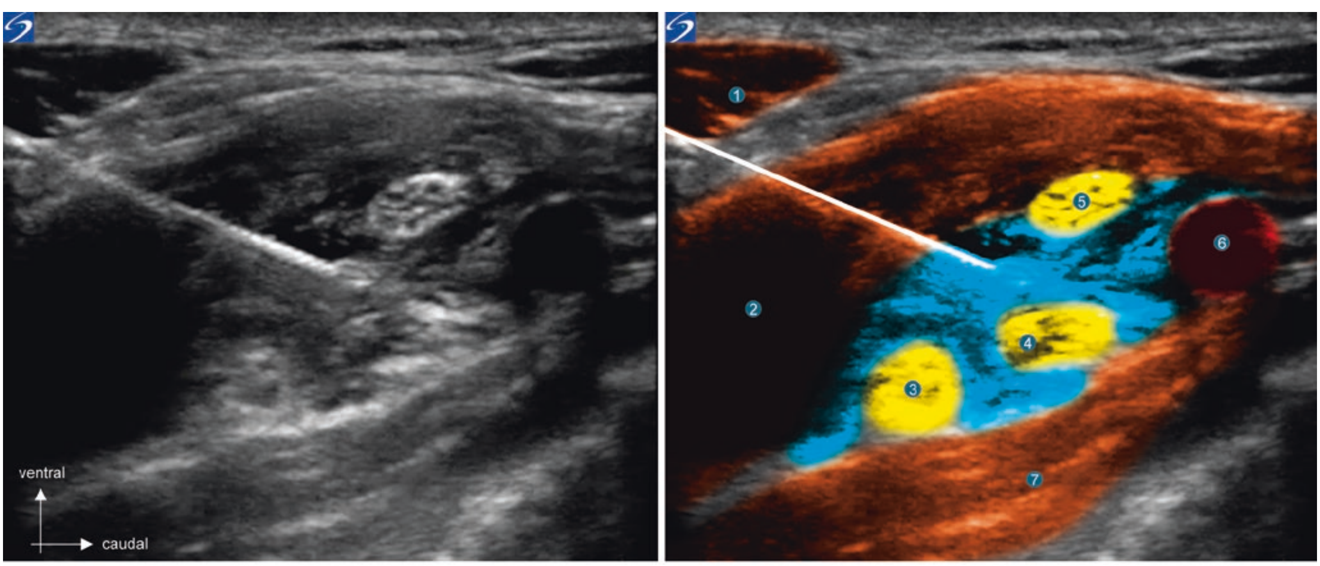
1. pleura
2. axillary v.
3. axillary a.
4. pectoralis minor m.
5. pectoralis major m.
6. lateral cord
7. medial cord
8. posterior cord

Fig. 5.69 Parasagittal infraclavicular ultrasound section of the brachial plexus

the target area encourages to use a so-called "hyperechoic" needle for this block. Additionally, neurostimulation is a useful safety aid during conduct of an ICB, especially considering the frequently poor visibility of the cords of the brachial plexus. Ideally, the objective is to position the tip of the needle in the dorsal aspect of the axillary artery, in proximity to the posterior cord. Generally, this leads to good local anaesthetic spread around the artery, in contact at least with the posterior and medial cords, but often of the three components and a complete block of the brachial plexus [58, 59]. By going from the superolateral border of the axillary artery to reach this position, the tip of the needle will first encounter the lateral cord. It is necessary to circumvent it dorsally, visually, and/or with the aid of neurostimulation ("median" and/or "musculocutaneous" responses). At this level, it is also possible to perform hydrodissection by injecting a few millilitres of a D5W solution which, by reinforcing the contrast between the different tissues, enables better identification of the lateral cord and facilitates its avoidance. It is necessary to be careful to avoid accidental pleural, pulmonary or vascular injury, by always keeping in mind the position of the tip of the needle and the structures to be avoided.

Injection

Once the needle visually is in place, obtaining "radial" responses to neurostimulation confirms the proximity of the posterior cord, and thus the correct position of the needle tip. However, it is also possible to observe other types of response (median or ulnar) if the medial cord is stimulated, often still



1. pectoralis major m.
2. pectoralis minor m.
3. posterior cord
4. medial cord
5. lateral cord
6. axillary a.
7. serratus m.

Fig. 5.70 Infraclavicular block. Spread of the local anaesthetic in contact with the cords

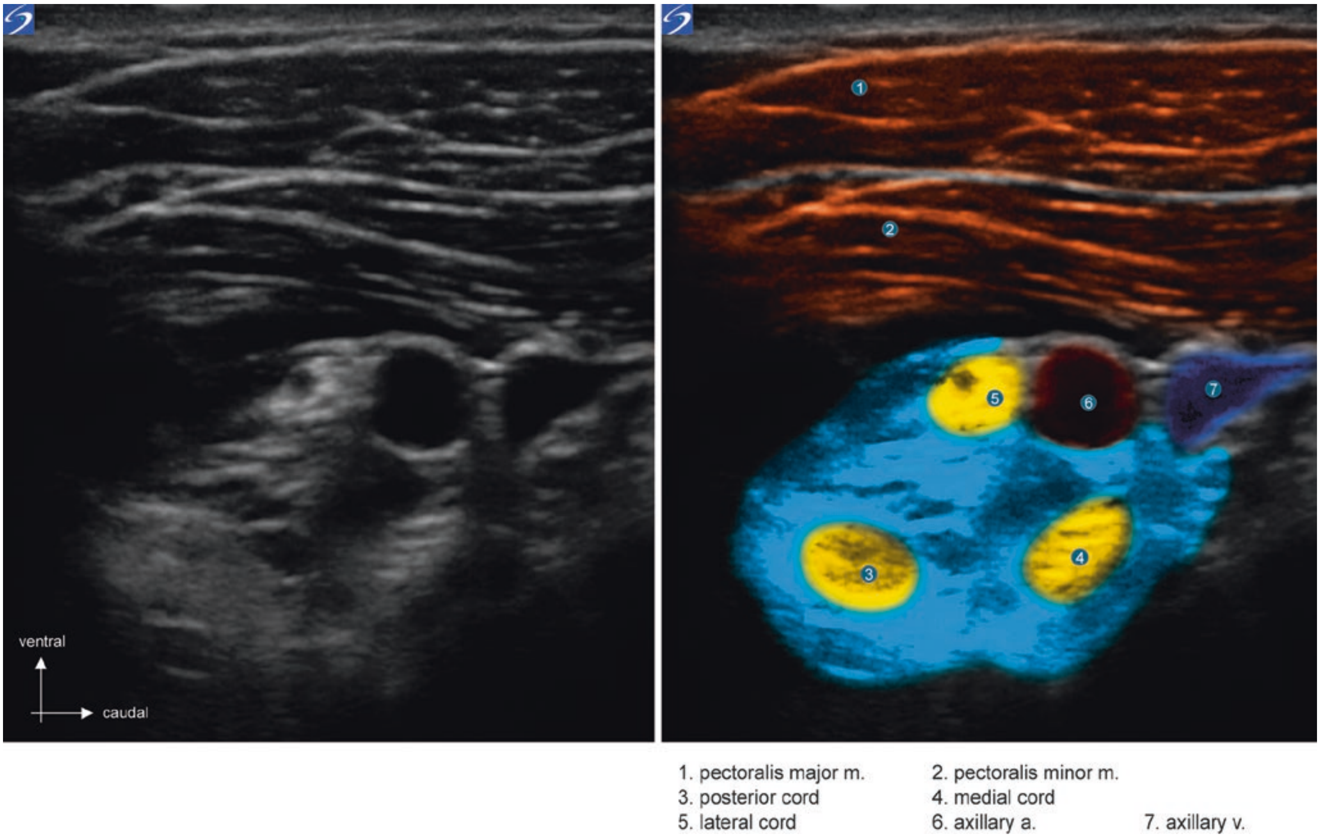


Fig. 5.71 Posterior surrounding of the axillary artery by the local anaesthetic injected with spread in contact with the three cords

placed behind the axillary artery (Fig. 5.70). The appearance of spread of the local anaesthetic is predictive of the efficacy of the block. Therefore, a main diffusion close to the posterior aspect of the axillary artery is synonymous with high probability of spread of the anaesthetic to the three cords (Fig. 5.71). In case of posterior "partitioning" of the local anaesthetic, after removing the needle, it is also possible to inject around the lateral cord and then to position oneself in front between the axillary artery and vein, and this time to inject in close to the medial cord. By going to the anterior aspect of the axillary artery, the lateral pectoral nerve and/or anastomotic branch with the medial pectoral nerve (pectoral muscles loop) can be found. In adults, a maximum volume of local anaesthetic of 20 mL is injected.

Paediatrics
In paediatrics, the infraclavicular nerve block is little used. In fact, although the target structures often are less deep than in adults (Fig. 5.72), the risks that it carries (pneumothorax, vascular injection) do not enable it to be used in routine practice. The axillary approach in principle should be preferred to it [60].

Axillary Nerve Block (Fig. 5.73)

Indications

The axillary block is indicated for hand surgery up to the elbow. With neurostimulation only, it is effective in almost 90% of cases. A single injection performed at the lower border of the deltoid muscle makes it possible to anaesthetise all of the terminal branches of the brachial plexus at this level as they form around the axillary artery. The injection can also selectively target the musculocutaneous nerve, which often takes a divergent course at this level and the smaller cutaneous nerves which supply sensation to the arm and forearm which may be involved in surgery. Compared to the supraclavicular and infraclavicular techniques, this approach eliminates the risk of pneumothorax and of phrenic nerve paresis. The trans-arterial technique no longer is recommended because of its low success rate and the high risk of haematoma compared to neurostimulation (professional consensus). As the result of the rarity of complications with the axillary approach, it remains the block technique of choice for distal surgery. The only drawback in trauma cases is the

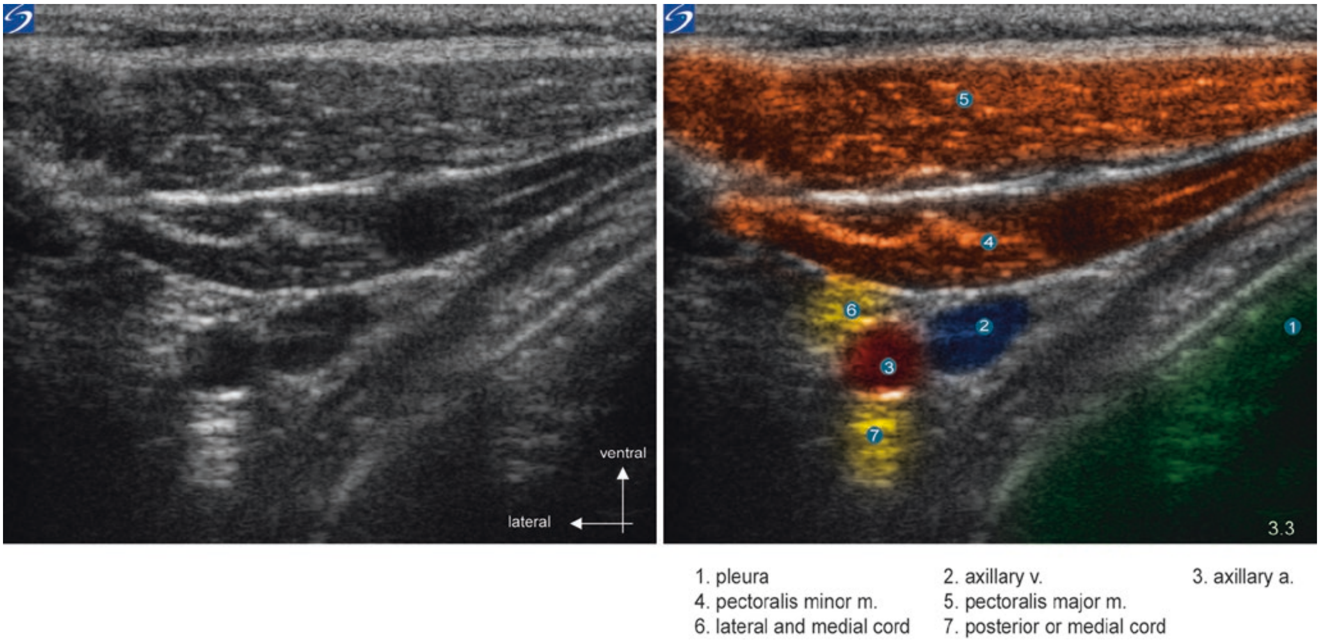


Fig. 5.72 Infraclavicular parasagittal ultrasound section in the brachial plexus in a 3-year-old child

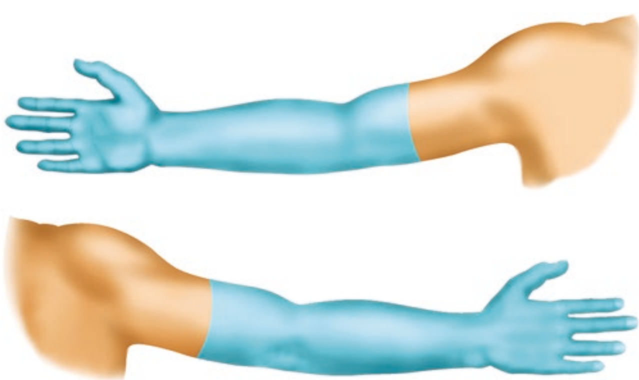


Fig. 5.73 Area of coverage of the axillary block

need to position of the patient's arm in 90° abduction. In this situation it is preferable to perform the infraclavicular approach [61].

It is also possible to site perineural catheters at this level.

Type of probe: linear, 5–10 or 6–13 MHz.
Axis of probe: transversal/short axis (Fig. 5.74).
Configuration: nerves in the short axis, needle in or out of the plane.
Depth studied: from 1 to 5 cm.
Neurostimulation: enables further identification of the nerves visualised and can limit, by determination of an MIS >0.3 mA (0.1 ms), the risk of accidental intrafascicular injection. Furthermore, it can supplement locating nerves when conditions of visibility are unfavourable.
Needle: 80 mm isolated, 22 G.
Utility of Doppler ultrasound: the brachial artery and veins, basilic vein.

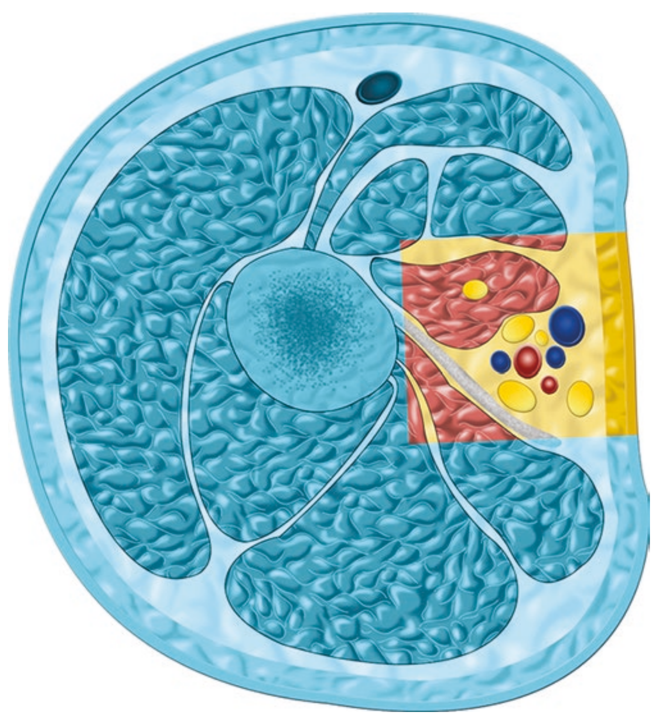
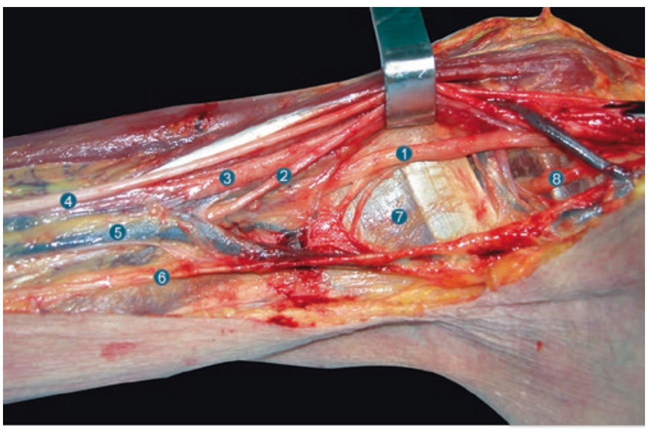


Fig. 5.74 Section of the proximal aspect of the arm with materialisation of the ultrasound beam for axillary block

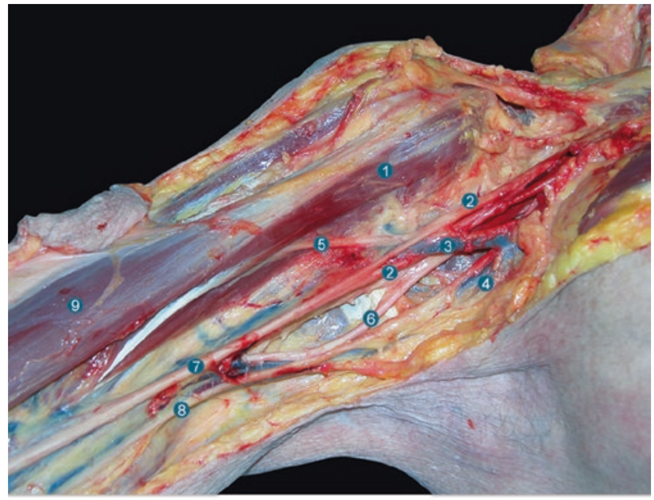
Echoanatomy and Approach
In order to obtain a precise and comprehensive view of the neurovascular structures, the probe is positioned transversely (Fig. 5.75). The ultrasound study in the upper brachial and axillary area is facilitated by the shallow depth of these structures in the majority of patients. Moreover, the predominant muscle constitution of the arm makes contrast of inter-tissue echogenicity favourable in locating and following the blood

Fig. 5.75 Ultrasound-guided axillary block. Position of probe



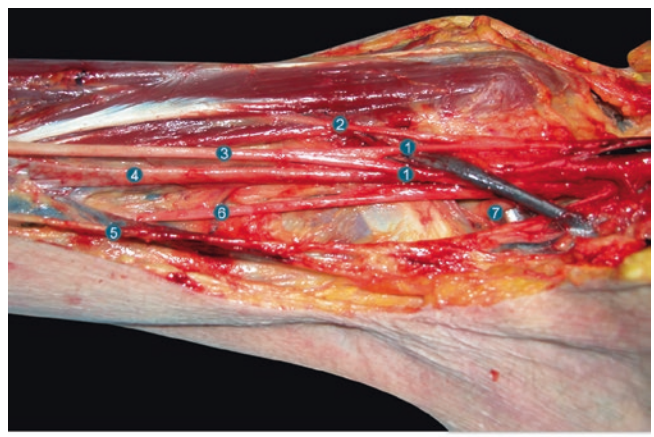
1. radial n. 2. ulnar n. 3. brachial a.
4. medial n. 5. basilic v.
6. medial antebrachial cutaneous n.
7. latissimus dorsi tendon 8. axillary n.

Fig. 5.76 Dissection of proximal end of the arm. Relations of the brachial plexus nerves with the tendon of the latissimus dorsi muscle. (Dissection: Bertrand Fabre)



1. coracobrachialis m.
2. terminal branches of lateral and medial cord composing median n.
3. brachial v. 4. basilic v. 5. musculocutaneous n.
6. ulnar n. 7. median n. 8. medial antebrachial cutaneous n.
9. biceps brachii m.

Fig. 5.77 Dissection of the brachial plexus in the proximal aspect of the arm. (Dissection: Bertrand Fabre)



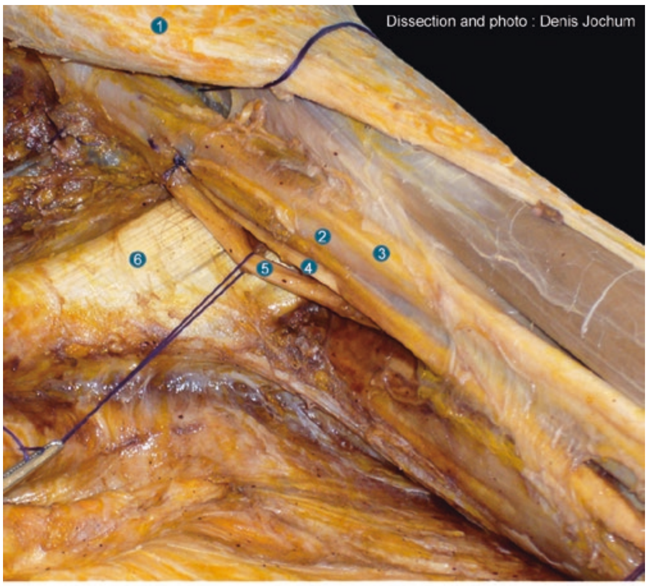
1. terminal branches of lateral and medial cord composing median n.
2. musculocutaneous n. 3. median n.
4. brachial a. 5. medial antebrachial cutaneous n.
6. ulnar n. 7. axillary n.

Fig. 5.78 Dissection at the proximal aspect of the arm. Relations of the brachial plexus nerves with the tendon of the latissimus dorsi muscle. (Dissection: Bertrand Fabre)

vessels and nerves. With ultrasound of the axillary fossa, with the patient's arm in abduction and probe perpendicular to the neurovascular axis (transverse), the terminal branches of the brachial plexus and the axillary blood vessels can be viewed together in a relatively compact neurovascular "bundle" (apart from the axillary nerve, which is no longer visible (Fig. 5.76) and the musculocutaneous nerve which often takes a divergent course at this level) (Figs. 5.77 and 5.78). However, in some cases the musculocutaneous nerve is immediately adjacent to the median nerve at this level. This observation can be compared to the cases of axillary block with pure neurostimulation during which the musculocutaneous nerve "cannot be found", and yet after injection of the local anaesthetic following a median nerve stimulus, it is anaesthetised by spread of the LA due to this close relationship. In many cases, precise identification of the nerve structures requires an ultrasound "status report": the distal and proximal translation of the probe (so-called "elevator" technique) is an excellent means to confirm identification of the anatomical elements. In fact, if ultrasound examination of a nerve is performed distally where its identity can be confirmed, it is then possible to track it proximally to determine its position in an area where its identification was less clear.

Just as for the more proximal approaches of the brachial plexus, the axillary approach enables anaesthesia of the terminal branches of the brachial plexus with a single cutaneous injection and a minimum of repositioning of the needle and a minimum of injections (apart from the subcutaneous injection for the medial cutaneous nerve in the arm).

In light of the size, position and orientation of the probe, the point of injection lies next to the anterior axillary fold (the groove which separates the biceps from the caudal border of the pectoralis major muscle). Therefore, this is a "proximal brachial approach", equivalent in terms of spread of the local anaesthetic to an "axillary" block with neurostimulator. For this reason, technically, the term *brachial* artery/vein should be used and not *axillary* artery/vein.



1. deltoid m. 2. brachial a. 3. median n.
4. ulnar n. 5. radial n. 6. latissimus dorsi tendon

Fig. 5.79 Position of the brachial plexus nerves overlying the tendon of the latissimus dorsi muscle

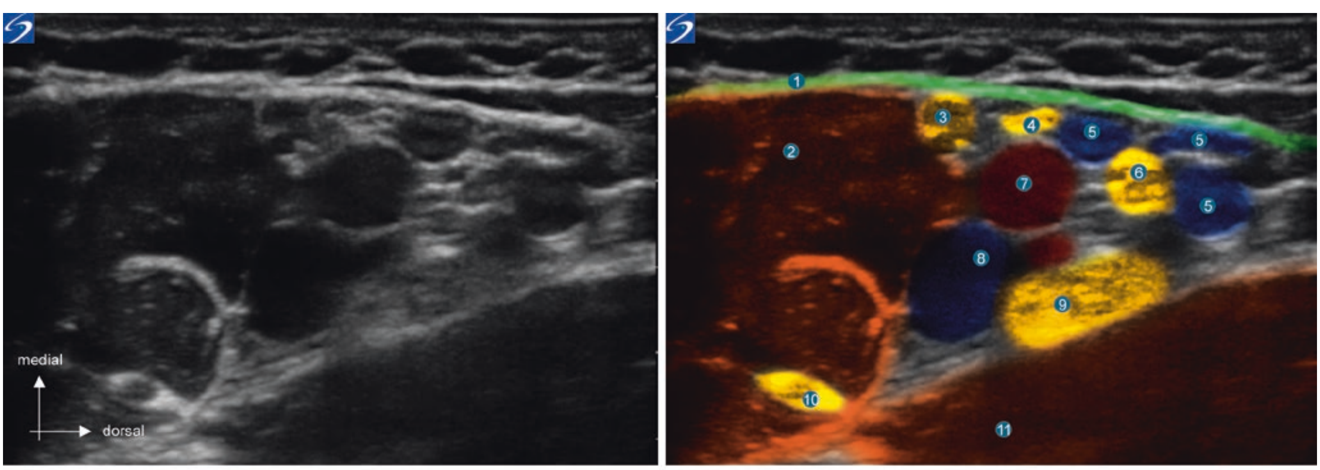
Nerve Localisation

To safely and successfully perform an axillary block is necessary to visualise and positively identify several structures: muscles, vessels (brachial artery and veins, basilic vein) and, of course, nerves. It is **essential** to locate the tendon of the latissimus dorsi muscle and its humeral insertion. Anterior to this tendon are combined all the terminal branches of the brachial plexus (apart from the axillary nerve) (Figs. 5.76, 5.77, 5.78 and 5.79). At the inferior border of this tendon the terminal branches of the brachial plexus begin their divergent pathways, particularly the radial nerve which quickly passes posteriorly into the radial groove of the humerus. If the clinician especially needs to target the radial nerve this position is ideal to perform the block.

By carefully positioning the probe, it is usually possible to visualise all the nerves to be anaesthetised on the same screen (Fig. 5.80). Therefore, from a single cutaneous injection site this enables an approach to each nerve with simple redirections of the needle.

Anatomical variations [62] are commonly detected during this initial scanning phase (Fig. 5.81) [63].

They can concern all the nerves in the brachial plexus. Note, for example in Fig. 5.82, that the median nerve is located at "6 o'clock" to the brachial artery. Figure 5.83 shows the median



1. brachial fascia 2. biceps brachii and coracobrachialis mm.
3. median n. 4. medial antebrachial cutaneous n.
5. vv. 6. ulnar n.
7. brachial a. 8. brachial v.
9. radial n. 10. musculocutaneous n.
11. latissimus dorsi m.

Fig. 5.80 Ultrasound-guided axillary block: overall view of neurovascular structures before performance of block

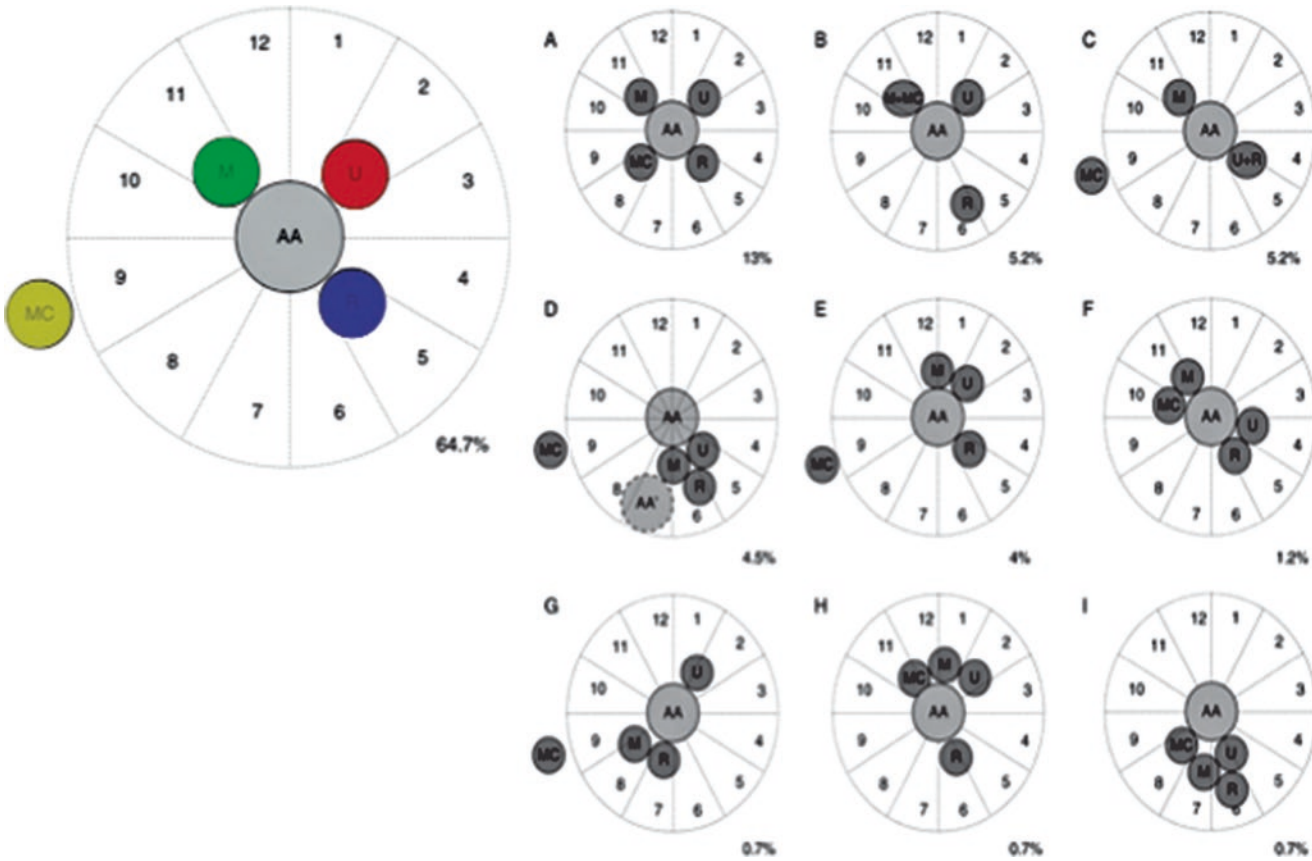
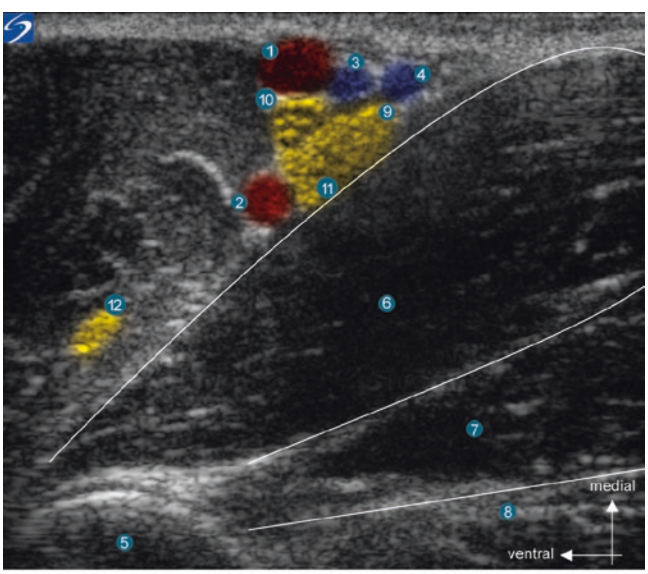


Fig. 5.81 Distribution of terminal branches of brachial plexus. (From [63])



1. brachial a.	2. deep brachial (profunda brachii) a.
3. brachial v.	4. basilic v.
5. humerus	6. latissimus dorsi tendon
7. teres major tendon	8. long head of triceps brachii m.
9. ulnar n.	10. median n.
11. radial n.	12. musculocutaneous n.

Fig. 5.82 "Axillary" transverse ultrasound section showing median nerve deep to the brachial artery

nerve located at the posterior border of the brachial artery and Fig. 5.84 represents the median nerve at the proximal brachial level consisting of two separate components which then unite more distally to form the single median nerve.

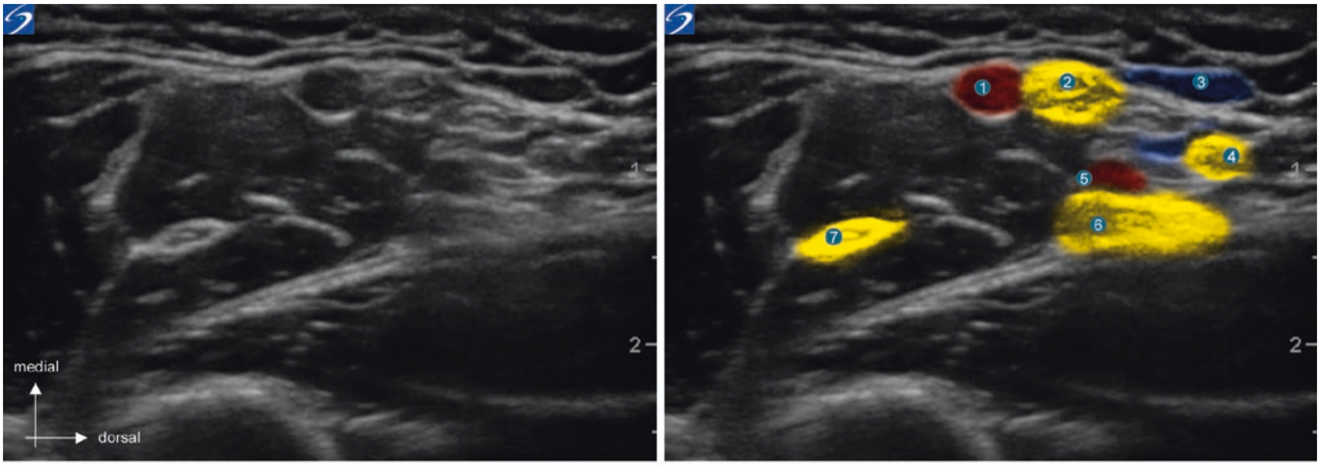
The position of the musculocutaneous nerve is also variable [64]. The latter is often found distant from the remainder of the neurovascular bundle between the biceps brachialis and coracobrachialis muscles. This can often require repositioning of the probe during the block but rarely a second cutaneous injection. Conversely, it is sometimes often found in immediate proximity to the median nerve with which it can give the impression of a "merging" [65].

Injection

Once the probe has been positioned, there are two methods to perform this block.

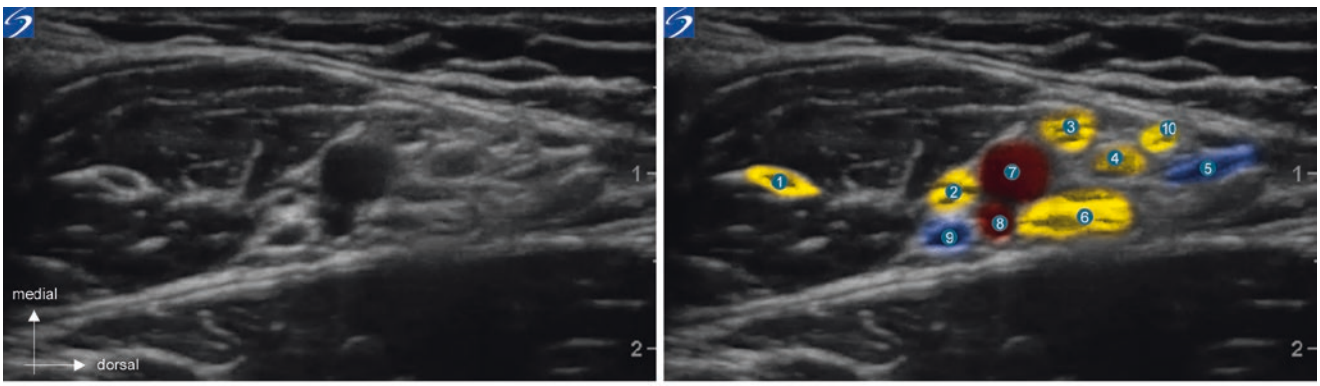
Needle in Plane (Fig. 5.85)

With the probe placed in the anterior axillary fold, the needle is inserted after local anaesthesia infiltration of the skin at the anterior end of the probe. The injection point is relatively similar to that of the technique of the infraclavicular block described by Dalens in children [66]. In order to maintain optimum visibility of all neurovascular structures throughout the procedure, it is important to start by injecting the local



1. brachial a. 2. median n. 3. basilica v.
4. ulnar n. 5. deep brachial (profunda brachii) a.
6. radial n. 7. musculocutaneous n.

Fig. 5.83 “Axillary” transverse ultrasound section showing median nerve dorsal to the brachial artery



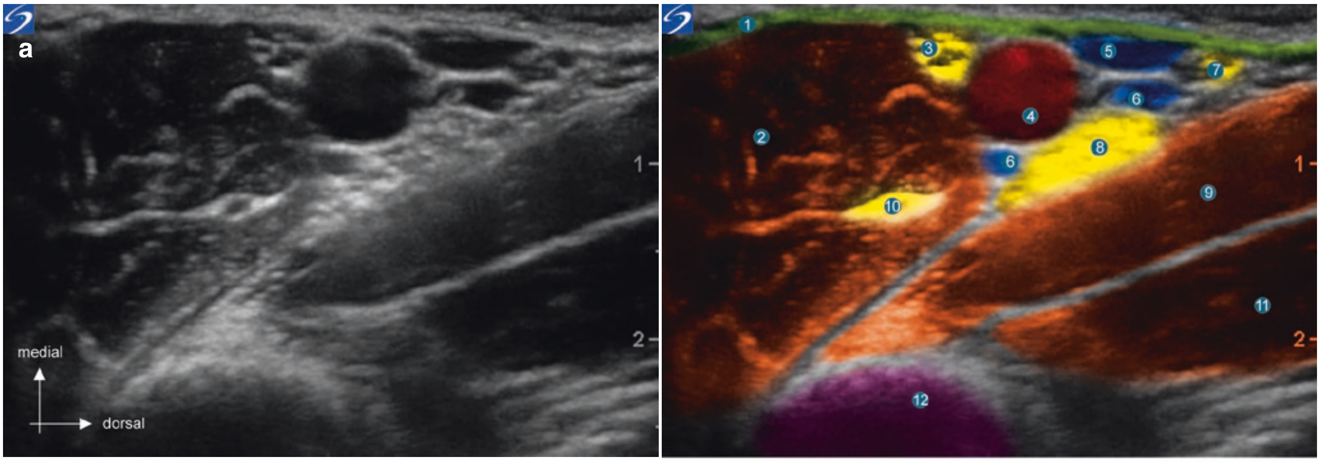
1. musculocutaneous n. 2. lateral median n. 3. medial median n.
4. ulnar n. 5. basilic v. 6. radial n.
7. brachial a. 8. deep brachial (profunda brachii) a.
9. brachial v. 10. medial antebrachial cutaneous n.

Fig. 5.84 “Axillary” transverse ultrasound section showing median nerve still comprised of two components which will merge more distally

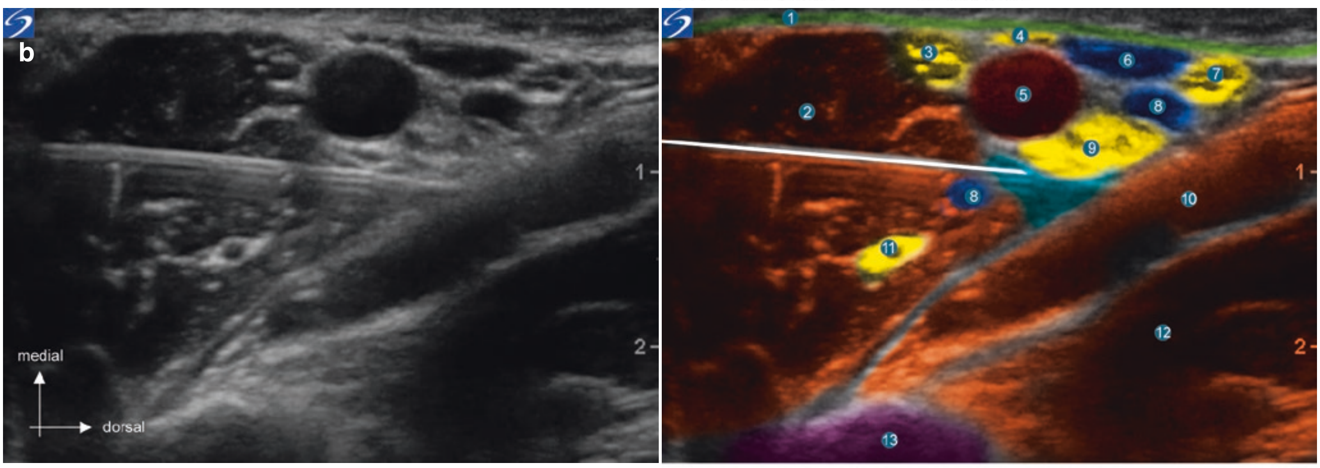
Fig. 5.85 Ultrasound-guided axillary block. Position of probe. Needle inserted in-plane

anaesthetic around the nerves that are furthest from the cutaneous injection site, i.e. the deepest ones, and then to block successively the more superficial nerves by withdrawing and/or redirecting the needle. In the case of inadvertent injection of a small amount of air or simply as the result of sonoanatomical degradation subsequent to the injection of the local anaesthetic, needle visibility may deteriorate and continuation of the block is then made more difficult and hazardous.

After crossing the aponeurosis of the biceps brachialis muscle, the needle is directed towards the radial nerve (Fig. 5.86a, b) which lies behind and deep to the brachial artery, often in the area of its acoustic enhancement. In this situation the combined use of US with neurostimulation is useful, by confirming that the tip of the needle is close to the nerve. Identification of the radial nerve can be aided by the noting the presence of the deep brachial artery, which

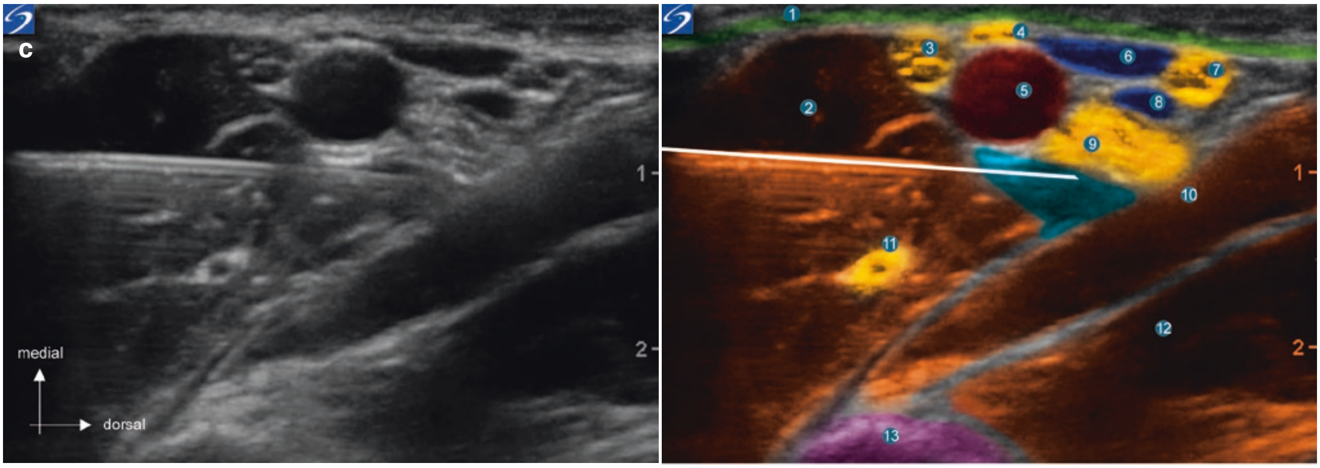


1. brachial fascia
2. biceps brachii and coracobrachialis mm.
3. median n.
4. brachial a.
5. basilic v.
6. brachial v.s
7. ulnar n.
8. radial n.
9. latissimus dorsi m.
10. musculocutaneous n.
11. teres major m.
12. humerus

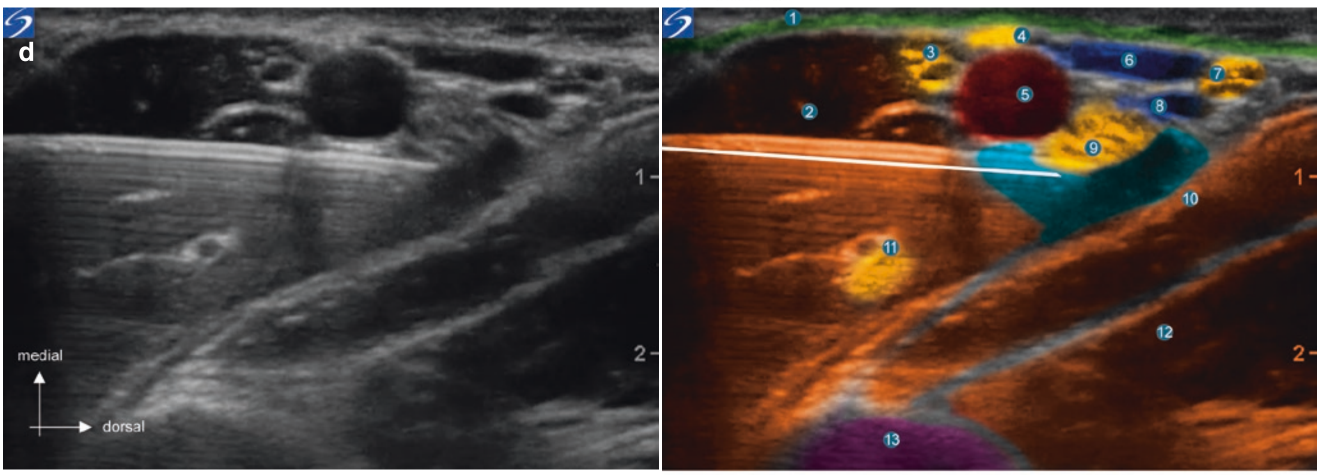


1. brachial fascia
2. biceps brachii and coracobrachialis mm.
3. median n.
4. medial antebrachial cutaneous n.
5. brachial a.
6. basilic v.
7. ulnar n.
8. brachial v.s
9. radial n.
10. latissimus dorsi m.
11. musculocutaneous n.
12. teres major and triceps brachii mm.
13. humerus

Fig. 5.86 Ultrasound-guided axillary block performed using an in-plane approach. (**a**) Transverse sonoanatomical section in axillary area. (**b**) Axillary block. Tip of needle in contact with radial nerve. (**c**) Axillary block: initial injection of local anaesthetic in contact with radial nerve. (**d**) Axillary block. Spread of local anaesthetic around radial nerve. (**e**) Axillary block. Needle in contact with median nerve, progressing towards the ulnar nerve, with aid of hydrodissection. (**f**) Axillary block. Needle in contact with medial cutaneous nerve of forearm, progressing towards the ulnar nerve with aid of hydrodissection. (**g**) Axillary block. Needle in contact with the ulnar nerve. (**h**) Axillary block. Injection of local anaesthetic in contact with ulnar nerve. (**i**) Axillary block. Spread of the local anaesthetic around the ulnar nerve. (**j**) Axillary block. Needle in contact with the median nerve, start of injection of local anaesthetic. (**k**) Axillary block. Injection and spread of local anaesthetic around the median nerve. (**l**) Axillary block. Injection of local anaesthetic in contact with the musculocutaneous nerve after sharply redirecting the needle

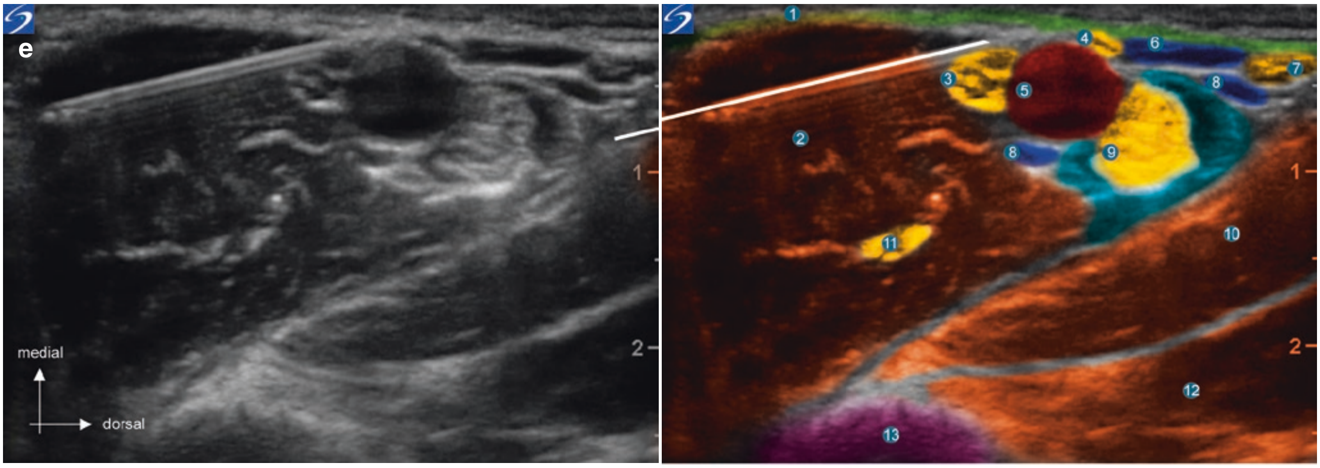


1. brachial fascia
2. biceps brachii and coracobrachialis mm.
3. median n.
4. medial antebrachial cutaneous n.
5. brachial a.
6. basilic v.
7. ulnar n.
8. brachial v.
9. radial n.
10. latissimus dorsi m.
11. musculocutaneous n.
12. teres major and triceps brachii mm.
13. humerus

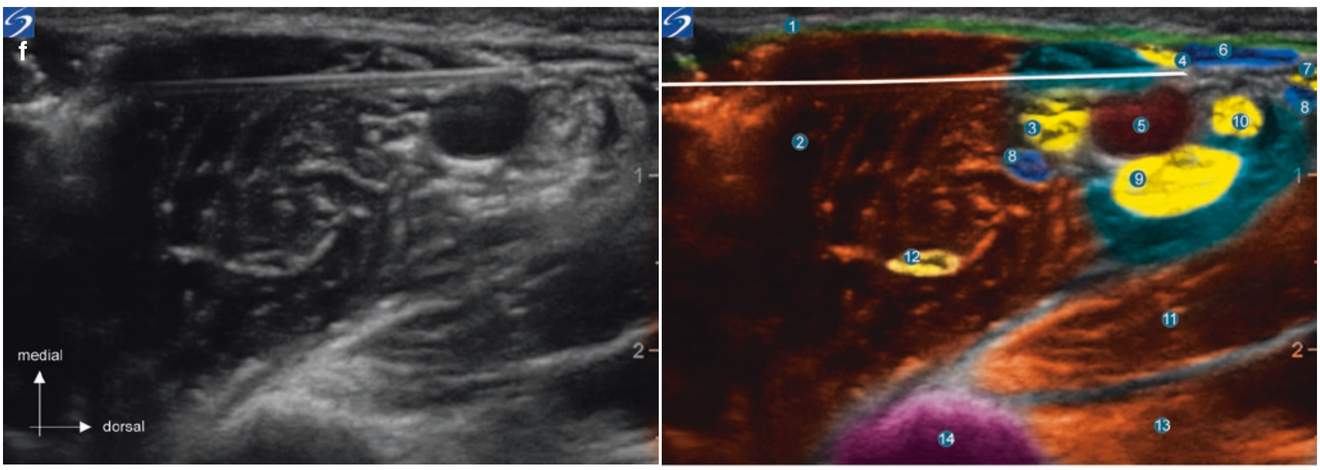


1. brachial fascia
2. biceps brachii and coracobrachialis mm.
3. median n.
4. medial antebrachial cutaneous n.
5. brachial a.
6. basilic v.
7. ulnar n.
8. brachial v.
9. radial n.
10. latissimus dorsi m.
11. musculocutaneous n.
12. teres major and triceps brachii mm.
13. humerus

Fig. 5.86 (continued)

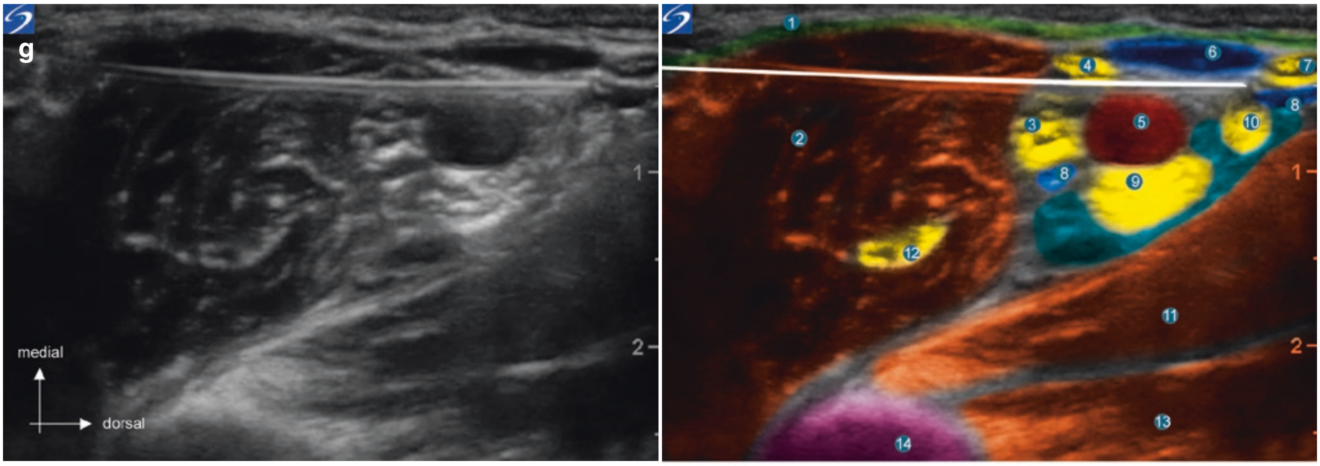


1. brachial fascia
2. biceps brachii and coracobrachialis mm.
3. median n.
4. medial antebrachial cutaneous n.
5. brachial a.
6. basilic v.
7. ulnar n.
8. brachial v.s
9. radial n.
10. latissimus dorsi m.
11. musculocutaneous n.
12. teres major and triceps brachii mm.
13. humerus

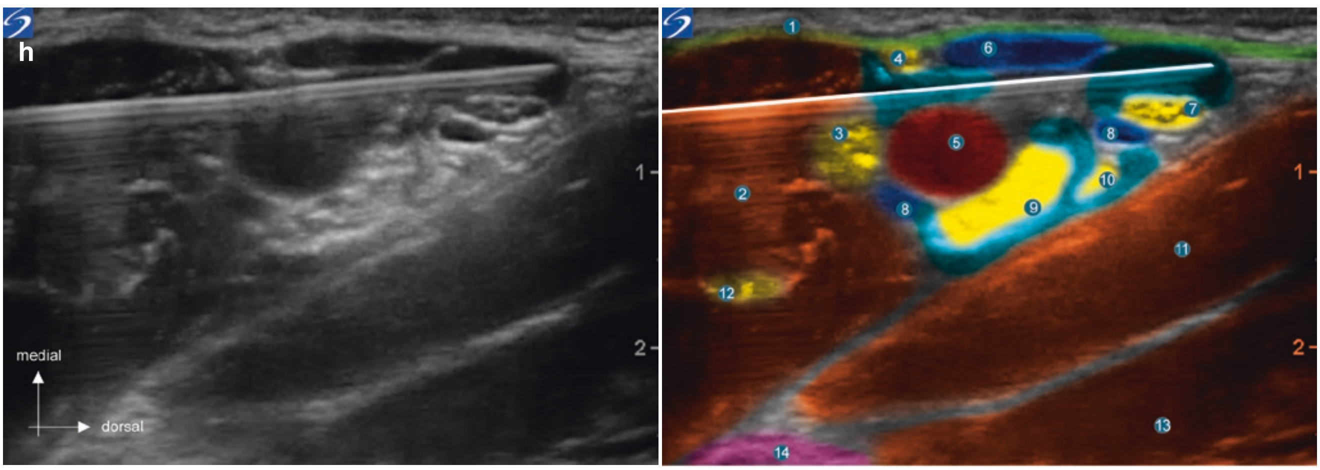


1. brachial fascia
2. biceps brachii and coracobrachialis mm.
3. median n.
4. medial antebrachial cutaneous n.
5. brachial a.
6. basilic v.
7. ulnar n.
8. brachial v.s
9. radial n.
10. motor branch of the long head of the triceps brachii m.
11. latissimus dorsi m.
12. musculocutaneous n.
13. teres major m.
14. humerus

Fig. 5.86 (continued)

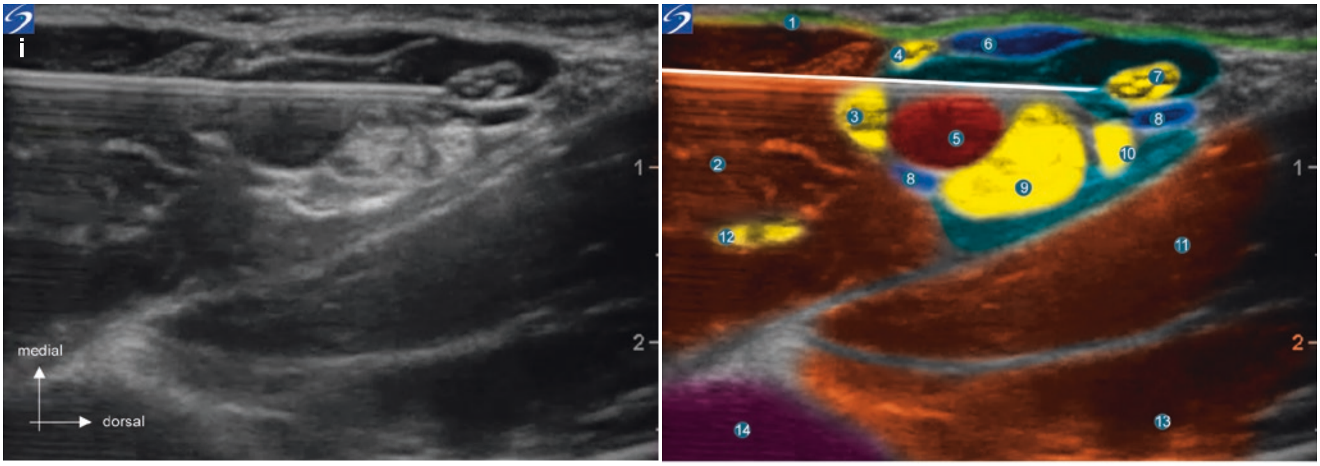


1. brachial fascia
2. biceps brachii and coracobrachialis mm.
3. median n.
4. medial antebrachial cutaneous n.
5. brachial a.
6. basilic v.
7. ulnar n.
8. brachial v.s
9. radial n.
10. motor branch of the long head of the triceps brachii m.
11. latissimus dorsi m.
12. musculocutaneous n.
13. teres major m.
14. humerus

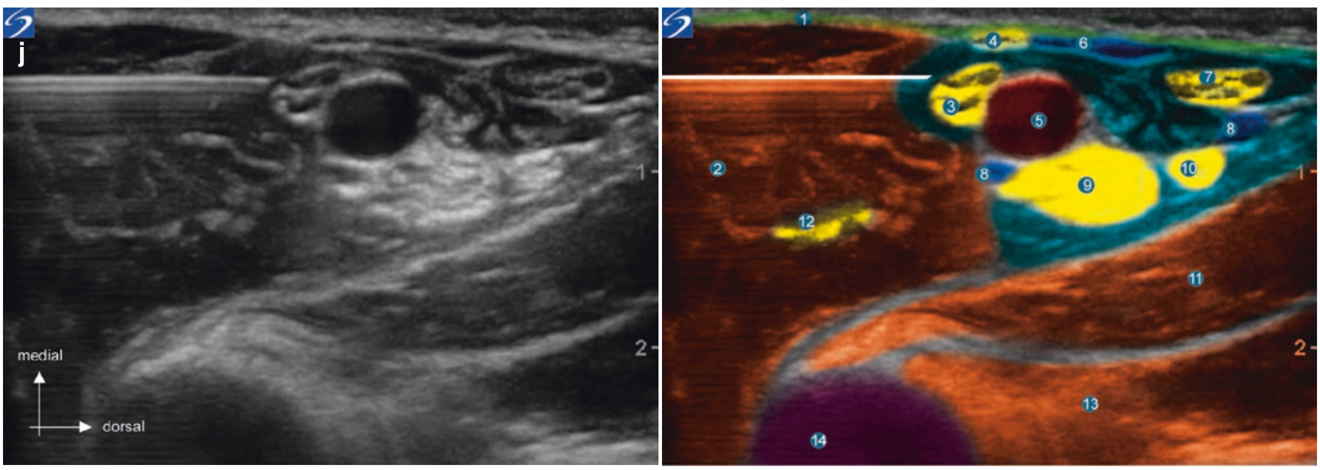


1. brachial fascia
2. biceps brachii and coracobrachialis mm.
3. median n.
4. medial antebrachial cutaneous n.
5. brachial a.
6. basilic v.
7. ulnar n.
8. brachial v.s
9. radial n.
10. motor branch of the long head of the triceps brachii m.
11. latissimus dorsi m.
12. musculocutaneous n.
13. teres major m.
14. humerus

Fig. 5.86 (continued)

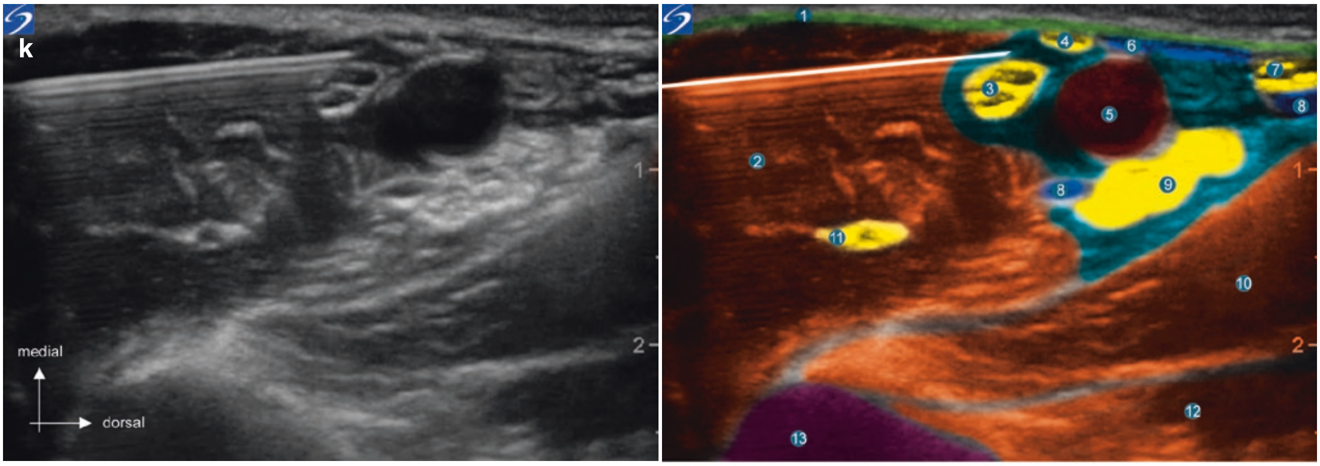


1. brachial fascia
2. biceps brachii and coracobrachialis mm.
3. median n.
4. medial antebrachial cutaneous n.
5. brachial a.
6. basilic v.
7. ulnar n.
8. brachial v.s
9. radial n.
10. motor branch of the long head of the triceps brachii m.
11. latissimus dorsi m.
12. musculocutaneous n.
13. teres major m.
14. humerus

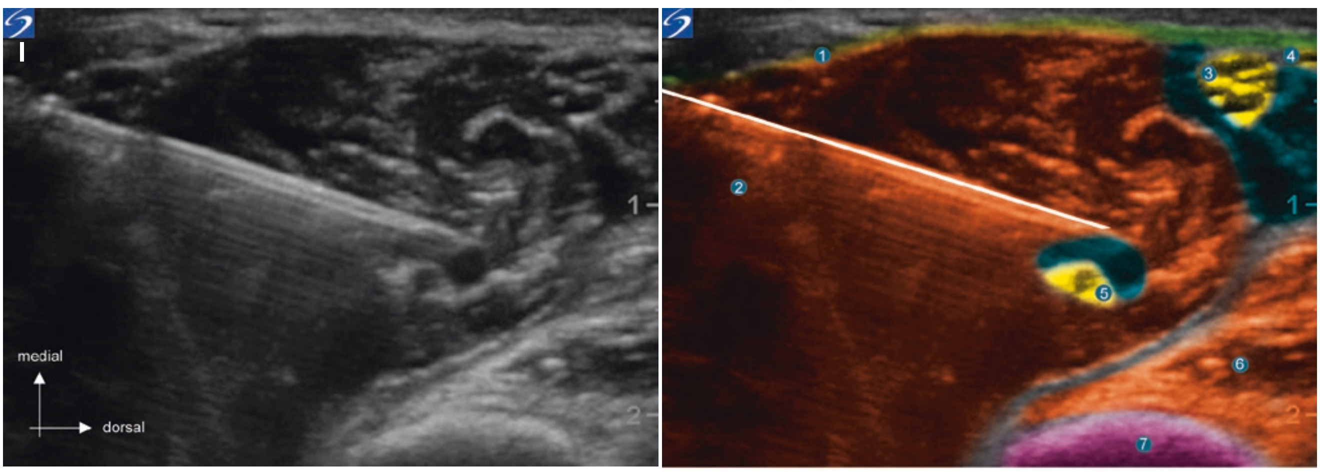


1. brachial fascia
2. biceps brachii and coracobrachialis mm.
3. median n.
4. medial antebrachial cutaneous n.
5. brachial a.
6. basilic v.
7. ulnar n.
8. brachial v.s
9. radial n.
10. motor branch of the long head of the triceps brachii m.
11. latissimus dorsi m.
12. musculocutaneous n.
13. teres major m.
14. humerus

Fig. 5.86 (continued)



1. brachial fascia
2. biceps brachii and coracobrachialis mm.
3. median n.
4. medial antebrachial cutaneous n.
5. brachial a.
6. basilic v.
7. ulnar n.
8. brachial v.s
9. radial n.
10. motor branch of the long head of the triceps brachii m.
11. latissimus dorsi m.
12. musculocutaneous n.
13. teres major m.
14. humerus



1. brachial fascia
2. biceps brachii and coracobrachialis mm.
3. median n.
4. medial antebrachial cutaneous n.
5. musculocutaneous n.
6. latissimus dorsi and teres major mm.
7. humerus

Fig. 5.86 (continued)

accompanies the nerve as it enters the radial groove of the humerus. By performing small proximal-distal movements of the probe, this artery can be visualised and thus define the position of the radial nerve. By injecting next to the radial nerve (Fig. 5.86b–d), the clinician looks to see if local anaesthetic spreads towards the ulnar nerve, which is often the case. Selective injection next to the ulnar nerve would then no longer be necessary [67–69]. If, however, the local anaesthetic does not spread towards the ulnar nerve, the needle is repositioned in order to block it next (Fig. 5.86e–i). After withdrawing and redirecting the needle, the local anaesthetic is then injected next to the median nerve (Fig. 5.86j, k). If the musculocutaneous nerve has not been covered by the local anaesthetic intended for the median nerve, the block is completed by withdrawing the needle almost to the subcutaneous level and redirecting it towards this nerve (Fig. 5.86l). At the end of the procedure, it should be verified that all the nerves have been adequately covered by the local anaesthetic. Considering the common anatomical variations that exist in the relative positions of each nerve and in the relative positions, number and size of the brachial blood vessels, the actual needle-nerve pathway to follow for each nerve is necessarily variable. Often it is necessary to pass the needle between the brachial artery and veins, or between the brachial artery and the median nerve. These adjustments are generally simple to perform but should be done attentively to avoid inadvertent vascular or nerve puncture. During needle insertion, it may be helpful to inject of small volumes (0.5–2 mL) of a D5W solution (hydrodissection) to create space for the needle and to improve contrast within the tissues (for example, to reach the ulnar nerve [Fig. 5.86e–g]). Note that it is necessary to perform medial subcutaneous injection only if it is desired to anaesthetise the area supplied by the medial cutaneous nerve **of the arm**. In fact, the medial cutaneous nerve **of the forearm**, which at this level is close to the basilic vein, is usually blocked during injection of the median nerve and/or ulnar nerve.

Needle Out of Plane

This is a technique which is rarely performed. In the author's opinion, it is useful only for a slightly shorter trajectory of the needle to reach the target nerves. However, this creates a greater risk of not identifying the true position of the needle tip possibly leading to inadvertent vascular/neural injection. In this configuration, constant pressure applied by the needle (and/or of the probe) results in compression of the venous network. Therefore, the potential for accidental venous puncture is greater and is accompanied by the risk of intravenous injection of LA or the rapid reabsorption of LA into the "injured" blood vessels. It should not to be used by inexperienced staff.

The probe is always positioned in the anterior axillary fold in order to obtain an image close to that of Fig. 5.86a. This time, the needle is inserted perpendicularly to the probe (Fig. 5.87), as in an axillary block with neurostimulation only. The practitioner should postively identify the position of the tip of the needle by scrupulously observing tissue movement. When combined with hydrolocalization these movements are a valuable indicator of position of the needle tip. As for the "in plane" approach previously described, it is necessary to start by blocking the deepest nerves. The local anaesthetic is injected successively next to the radial nerve, the ulnar nerve and median nerve, and lastly the musculocutaneous nerve.

Fig. 5.87 Axillary block. Injection using an out-of-plane approach

Insertion of a Perineural Catheter

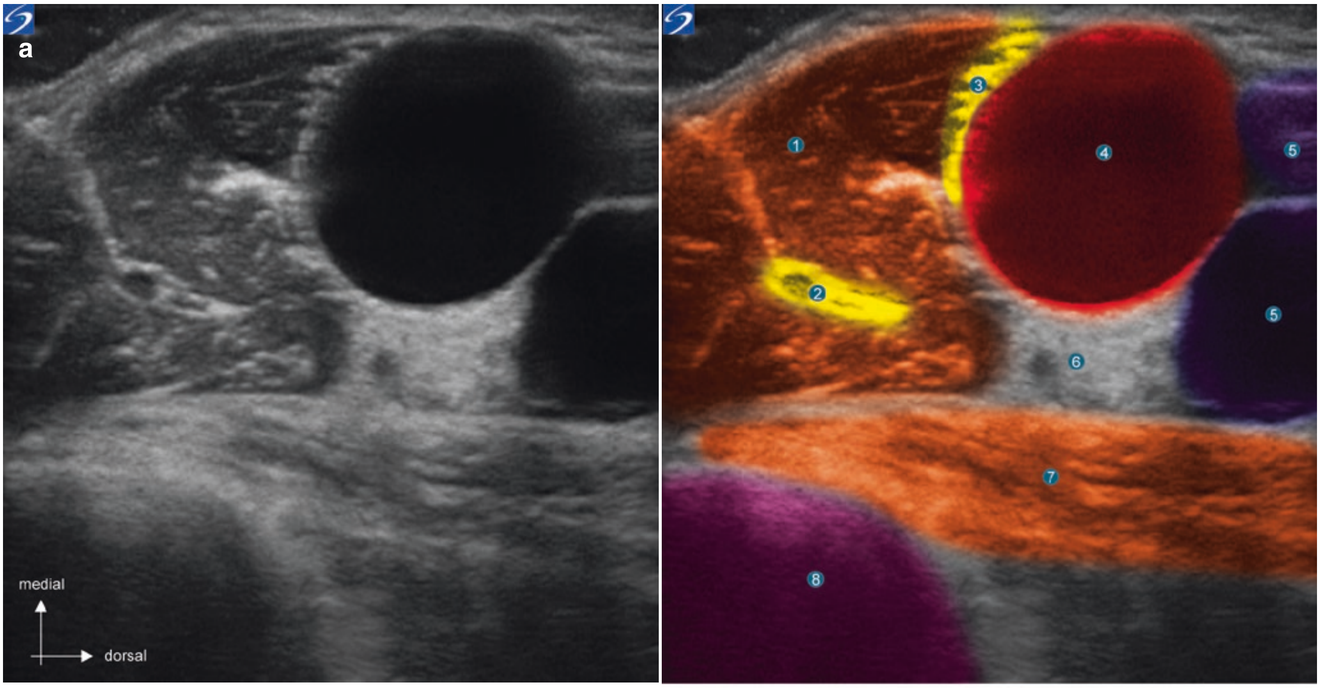
As has been already stated, if we insert a perineural catheter during an axillary block, depending on where the tip is finally positioned its effect may be more pronounced in the sensory territory of one nerve or another, e.g. in the radial and/or ulnar nerve area, or median nerve area or even the musculocutaneous nerve area. If when establishing the block, LA injection is performed around all the nerves, the initial overall efficacy will subsequently give rise to more selective anaesthesia/analgesia, depending on the precise site of distribution of low flow of the LA through the catheter. This process should guide positioning of the tip of the catheter so that it can be placed near to the nerve(s) which will produce the best quality of analgesia continuing beyond the regression of the initial block.

Paediatrics

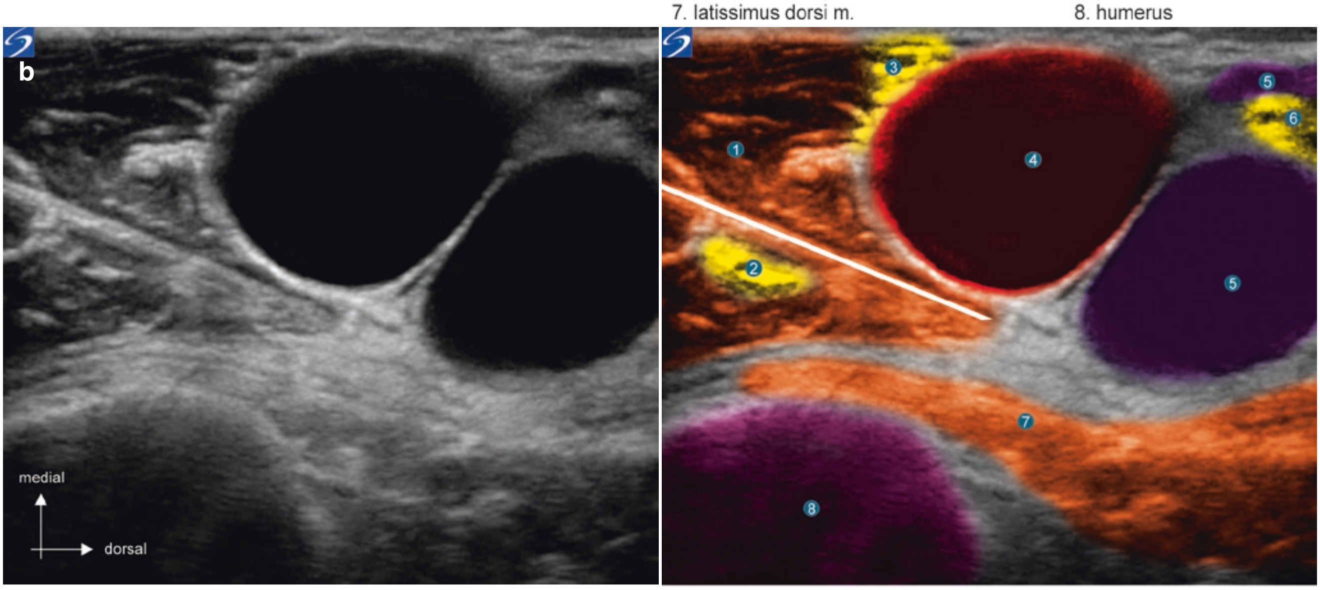
The depth of the neurovascular bundle is that much shallower in the younger child. This requires appropriate equipment if one wishes to obtain precise images of anatomical structures, their position and the injection procedure. Therefore, higher frequency probes (15 MHz) should be used with appropriate adjustment of the focal point to optimise the quality of the scan.

Patients with an Arteriovenous Fistula (AVF)

The axillary block is a routine procedure in the case of AVF surgery in a patient with renal impairment [70], and also in the setting of nonvascular surgery (orthopaedics and trauma). When scanning the axilla in a limb which has an AVF, there is a large increase in size of the brachial, axillary and basilic veins (Fig. 5.88a). The nerves of the brachial plexus are found entangled between the blood vessels and there is a high risk of intravascular injection. To avoid this, ultrasound guidance should be the technique of choice in such fragile patients. The images in Fig. 5.88a–g summarise a safer approach to the axillary block in this situation. This involves an axillary block with a transversely applied probe, with the needle inserted and visualised in-plane (the out-of-plane technique is strongly not recommended).

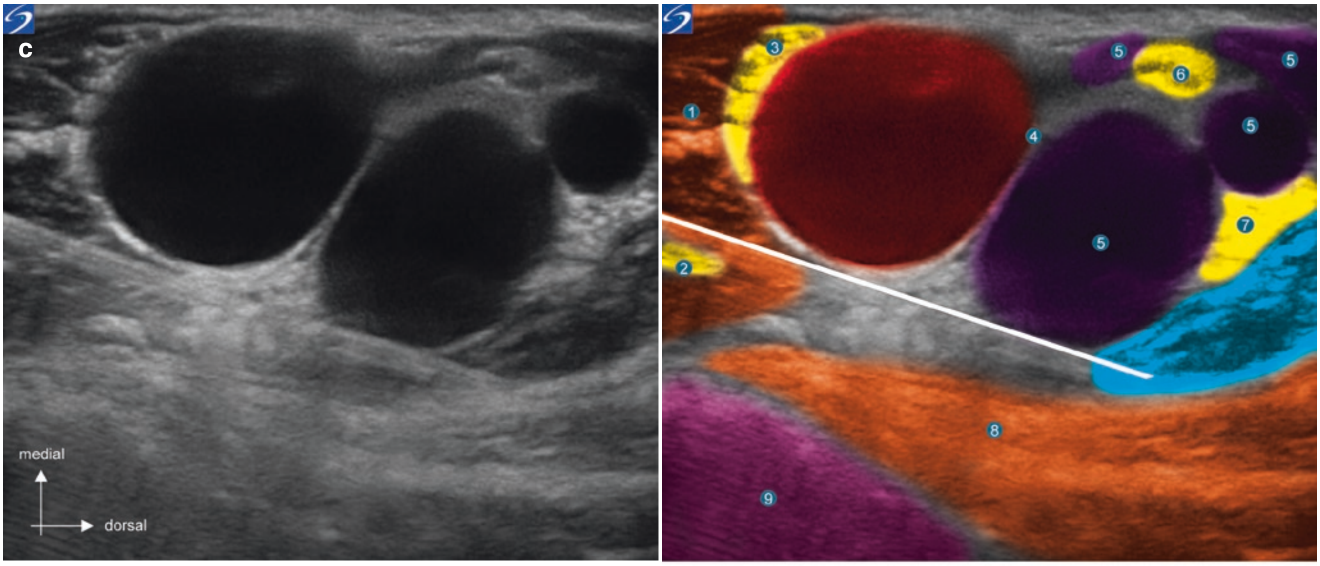


1. biceps brachii and coracobrachialis mm.
2. musculocutaneous n.
3. median n.
4. brachial a.
5. arterialized vv.
6. posterior reinforcement
7. latissimus dorsi m.
8. humerus

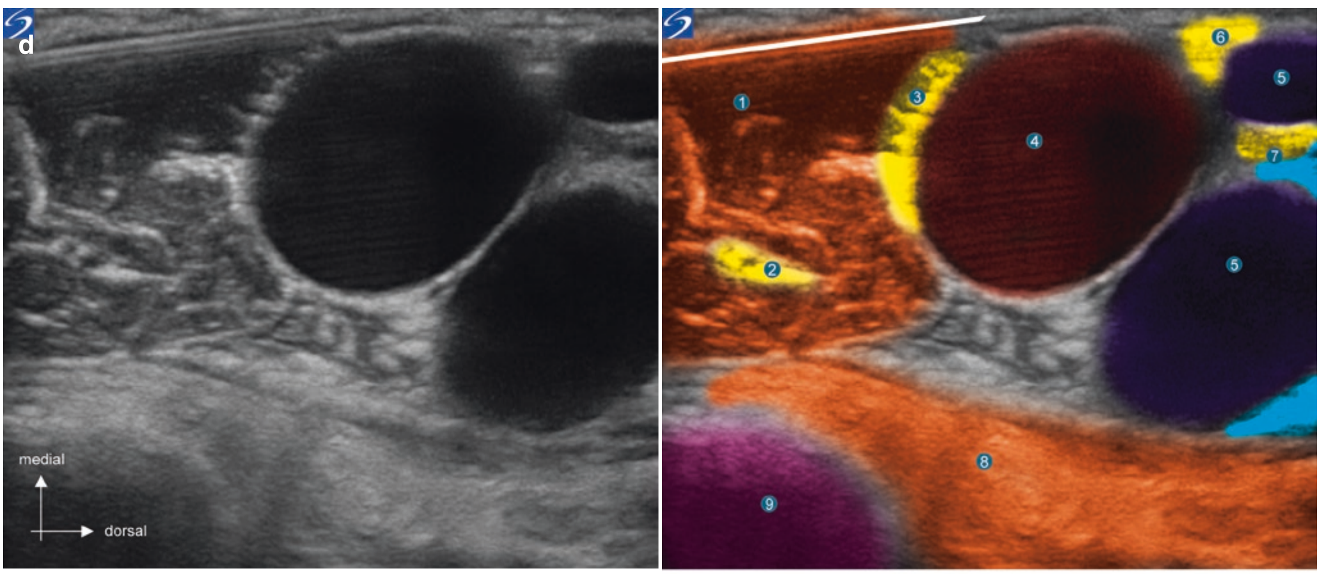


1. biceps brachii and coracobrachialis mm.
2. musculocutaneous n.
3. median n.
4. brachial a.
5. arterialized vv.
6. ulnar n.
7. latissimus dorsi m.
8. humerus

Fig. 5.88 Axillary block in a patient with an arteriovenous fistula. (**a**) Transverse section in axillary level. (**b**) Initial approach of needle towards the plane deep to the blood vessels. (**c**) Injection of local anaesthetic in contact with radial nerve. (**d**) Redirection of the needle in a plane superficial to blood vessels aiming towards the ulnar nerve. (**e**) Approach and injection of local anaesthetic in contact with the ulnar nerve with the aid of hydrodissection. (**f**) Withdrawal of the needle with, in passing, an injection of local anaesthetic in contact with the median nerve. (**g**) After redirection of the needle, the local anaesthetic is deposited in contact with the musculocutaneous nerve

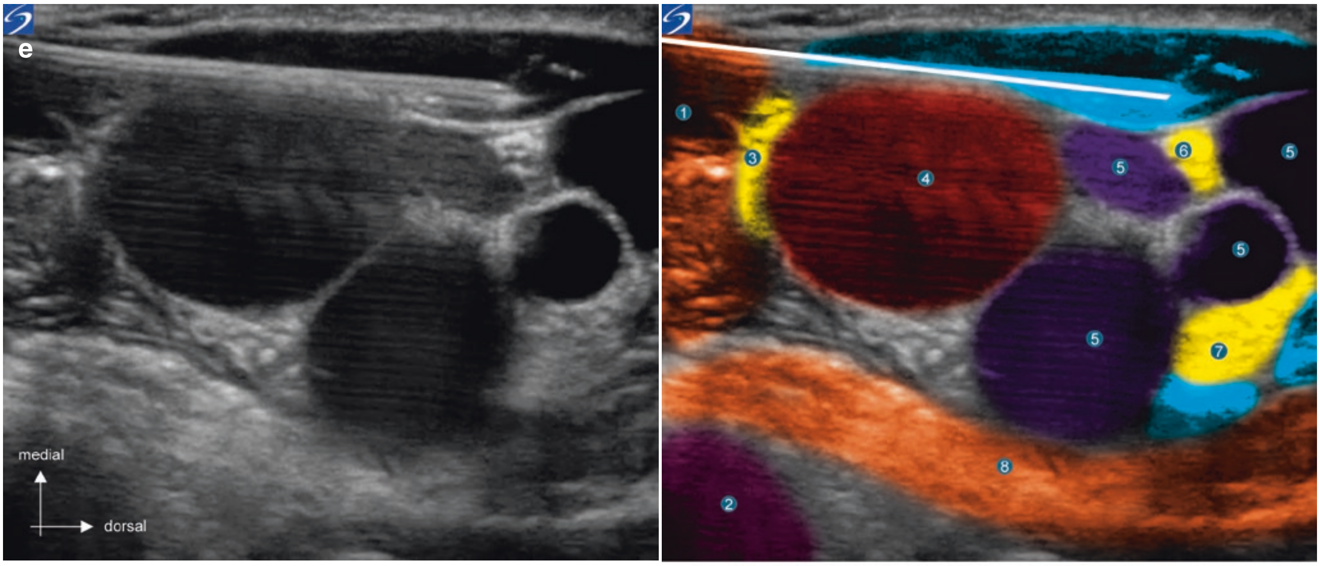


1. biceps brachii and coracobrachialis mm. 2. musculocutaneous n.
4. brachial a. 5. arterialized vv. 6. ulnar n.
7. radial n. 8. latissimus dorsi m. 9. humerus

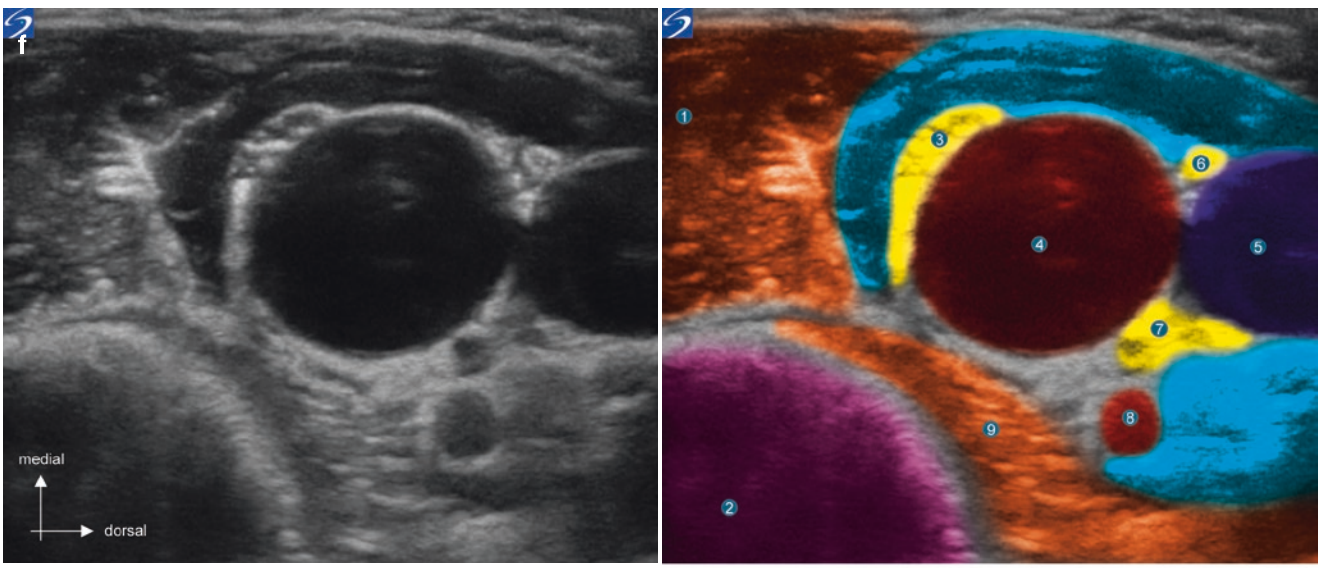


1. biceps brachii and coracobrachialis mm. 2. musculocutaneous n.
3. median n. 4. brachial a. 5. arterialized vv.
6. ulnar n. 7. radial n. 8. latissimus dorsi m.
9. humerus

Fig. 5.88 (continued)



1. biceps brachii and coracobrachialis mm.
2. humerus
3. median n.
4. brachial a.
5. arterialized vv.
6. ulnar n.
7. radial n.
8. latissimus dorsi m.



1. biceps brachii and coracobrachialis mm.
2. humerus
3. median n.
4. brachial a.
5. arterialized vv.
6. ulnar n.
7. radial n.
8. deep brachial (profunda brachii) a.
9. latissimus dorsi m.

Fig. 5.88 (continued)

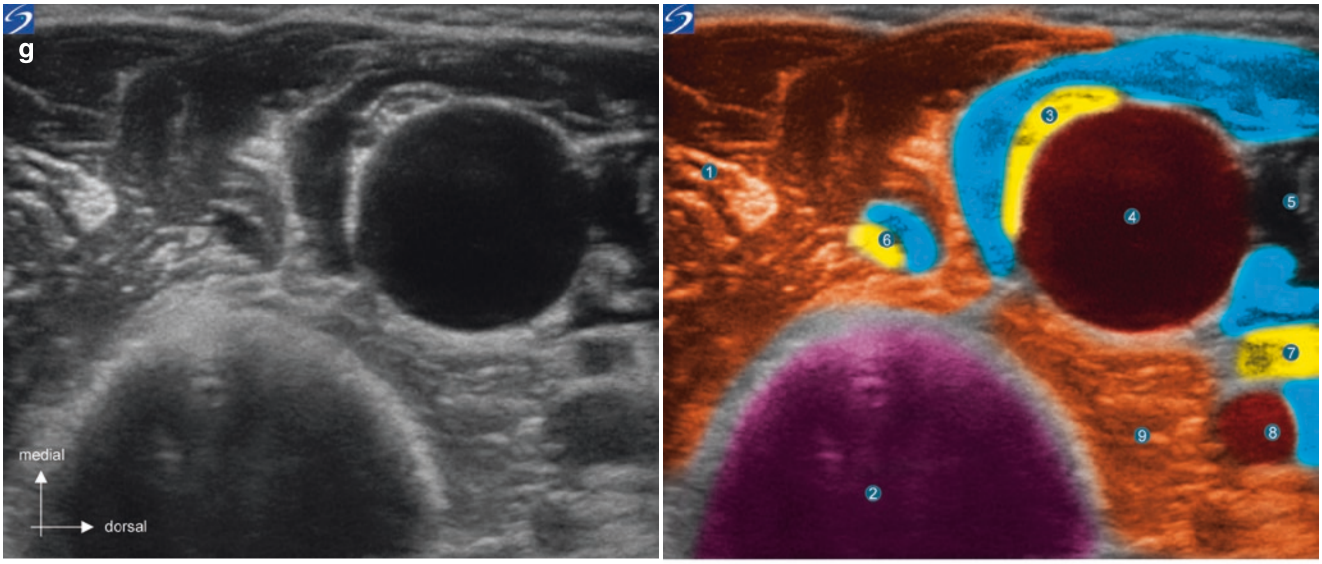


Fig. 5.88 (continued)

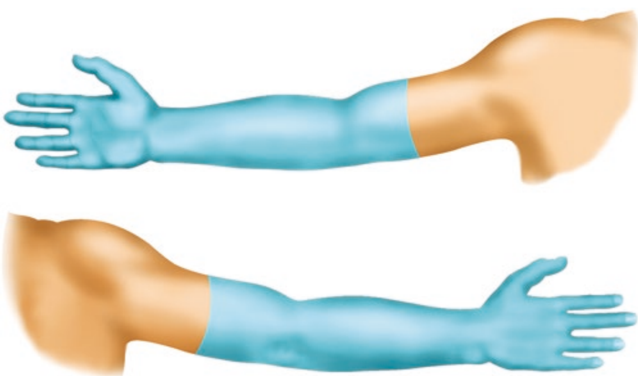


Fig. 5.89 Area of coverage of the block in the brachial canal

Brachial Canal Block (Fig. 5.89)

Indications

The nerve block in the brachial canal (humeral canal) is routinely used for surgery of the upper limb (professional consensus). Good results are obtained by anaesthesiologists whether experienced or not, and for Carles et al. [70], the failure rate is less than 5%. The order of injection varies according to authors: median, radial, ulnar, and then musculocutaneous nerve according to Gaertner et al. [71, 72] while Güntz [73] recommends starting with the radial nerve, the deepest.

It allows differential anaesthesia to be performed on the 4 main nerves of the upper limb. With neurostimulation alone, there may be concerns in stimulating nerves that are situated close together and possibly injuring a nerve already anaesthetised which has become non-stimulable with a traditional moderate electrical current (1.5 mA for 0.1 ms). Visual control enabled by using ultrasound can offer some reassurance on this point. This block enables surgery of the hand up to the elbow, sometimes with need to block the branches of the medial cutaneous nerve in the arm by subcutaneous infiltration (and also the posterior cutaneous nerve in the arm for elbow surgery). Indications for brachial canal block are minor surgery from the elbow down and hand surgery. As for an axillary block, the position of the patient's arm in abduction may be a drawback for injured patients.

Compared to the previously described axillary block, the utility of ultrasound-guided brachial canal approach is essentially the possibility of performing selective or differential blocks, with the nerves being further from each other than in the axillary level. A perineural catheter also can be inserted in contact with the nerve trunk for which prolonged action is desired (anaesthetic or analgesic).

Type of probe: linear, 5–10 or 6–13 MHz.
Axis of probe: transversal (Fig. 5.90).
Configuration: nerves in short axis, needle in or out of the plane.
Studied depth: 1–5 cm.
Neurostimulation: enables further identification of the nerves visualised and can limit, by determination of an MIS >0.3 mA (0.1 ms), the risk of accidental intrafascicular injection. Furthermore, it can supplement locating nerves when conditions of visibility are unfavourable.
Needle: 50–80 mm isolated, 22 G.
Utility of Doppler ultrasound: brachial artery and veins, basilic vein.

Echoanatomy

As in the (proximal) axillary block, US scanning in the humeral canal generally benefits from the shallow depth of the neurovascular structures in the majority of patients. This is less true for the radial nerve, which has already started its descent into the radial groove of the humerus. It is much deeper and sometimes difficult to visualise in the mid-humeral position. However, apart from the axillary and medial cutaneous nerve of the arm, the humeral canal approach allows anaesthesia of all major terminal branches of the brachial plexus from a single cutaneous injection site.

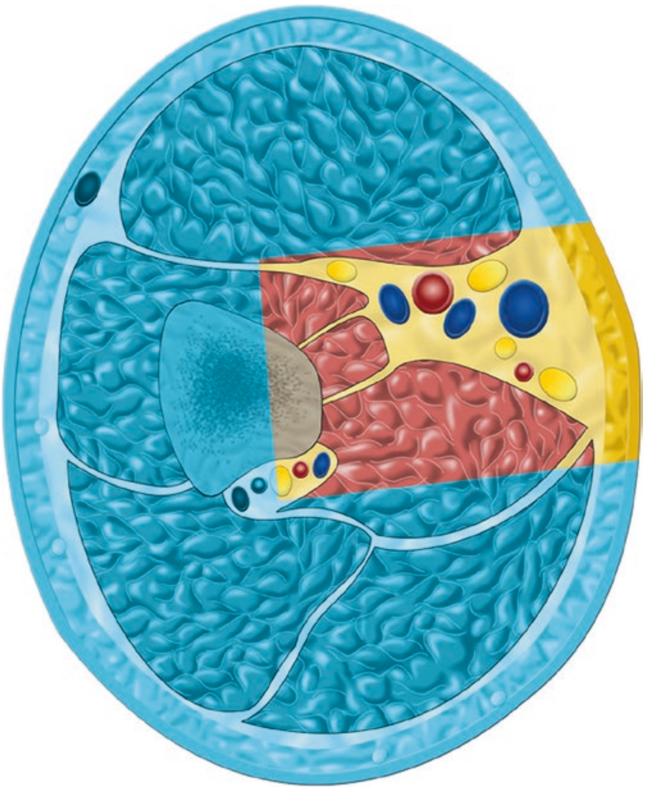


Fig. 5.90 Section of arm in the brachial canal with materialisation of the ultrasound bundle

Localization

The probe is positioned transversely. The important structures to visualise are vascular (brachial artery and veins, basilic vein), muscular and bone (humerus). Although it is not constant, it is often possible to visualise on the same screen all the terminal branches of the brachial plexus at this level. When this is the case, it is possible with a single injection site, to approach each nerve with simple axial redirection of the needle. However, the musculocutaneous nerve may already be laterally distant from the other nerve elements, and divided into its different branches (motor branches and terminal sensory branch). Occasionally, the musculocutaneous nerve is in immediate proximity to the neurovascular bundle (Fig. 5.91). The radial nerve, which is deep, may already be behind the acoustic shadow of the humerus. This can be an obstacle to a single injection, thus requiring an additional injection at the posterior end of the probe or a separate, more distal block of the radial nerve performed at the elbow. The medial cutaneous nerve in the forearm, which follows the basilic vein, often is relatively well-visualised (Fig. 5.92). Sometimes, the median nerve may be seen already posterior to the brachial artery (Fig. 5.93).

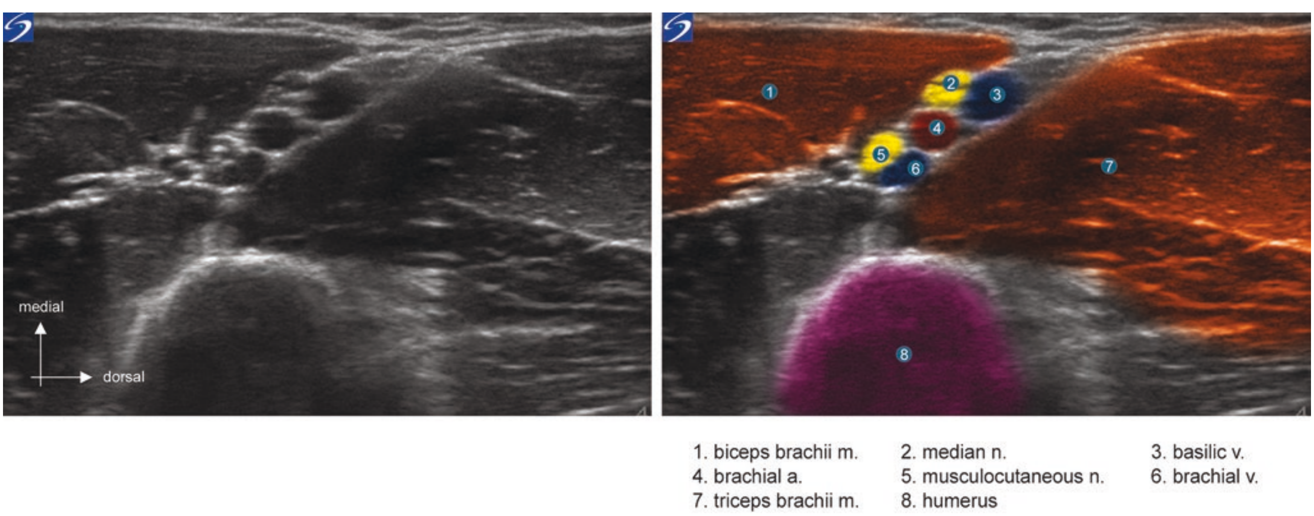


Fig. 5.91 Brachial canal block. Musculocutaneous nerve in proximity to the neurovascular bundle

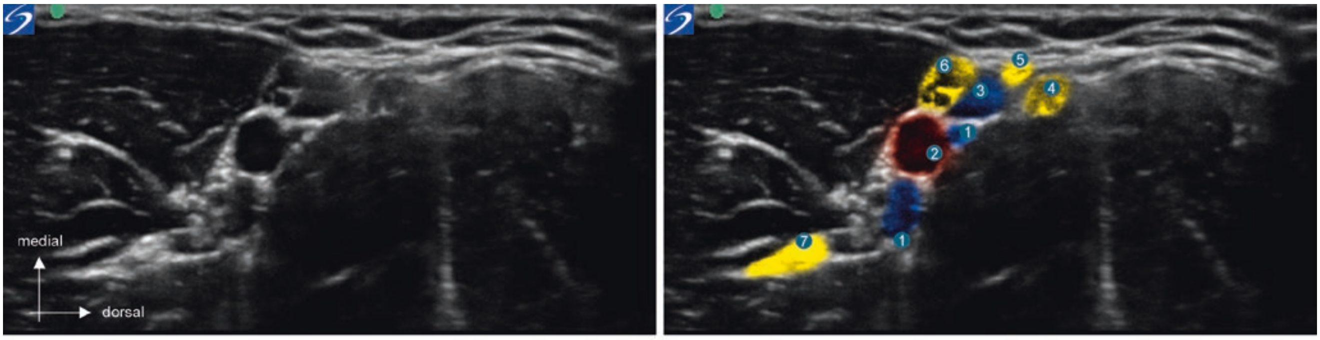


Fig. 5.92 Brachial canal block. The medial cutaneous nerve of the forearm is clearly visible

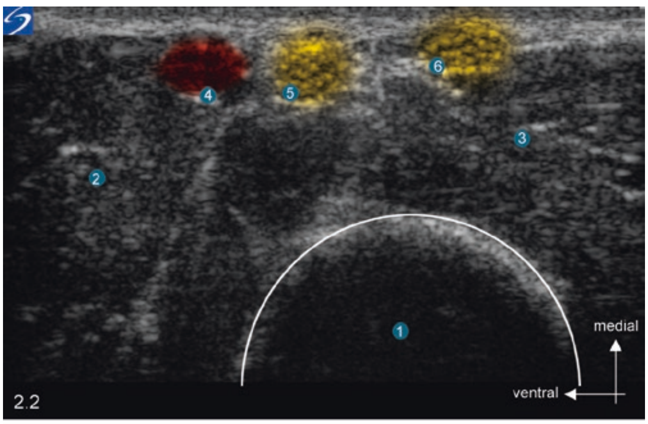


Fig. 5.93 Transverse ultrasound section in the brachial canal displaying the median nerve posterior to the artery while the musculocutaneous and radial nerves no longer appear in the field

Fig. 5.94 Block in the brachial canal. Needle inserted in-plane

Injection

As with performing a block at the axillary level, the needle can be visualised in-plane with it being inserted either at the anterior end (Fig. 5.94) or posterior end of the probe, or placed out-of-plane, by inserting it laterally to the probe. Once the skin has been punctured the process of needle redirection is the same as that for the axillary approach. However, due to the major nerves diverging at this level, when using an in-plane approach it may be necessary to make a second posterior injection to place the needle more closely to the radial nerve (Fig. 5.95). As in the axillary approach, it is recommended to start by injecting the local anaesthetic around the deepest nerves (radial and musculocutaneous), in order to not be hindered by injection artefacts, as may be the case when starting the block by injecting the LA around most superficial nerves.

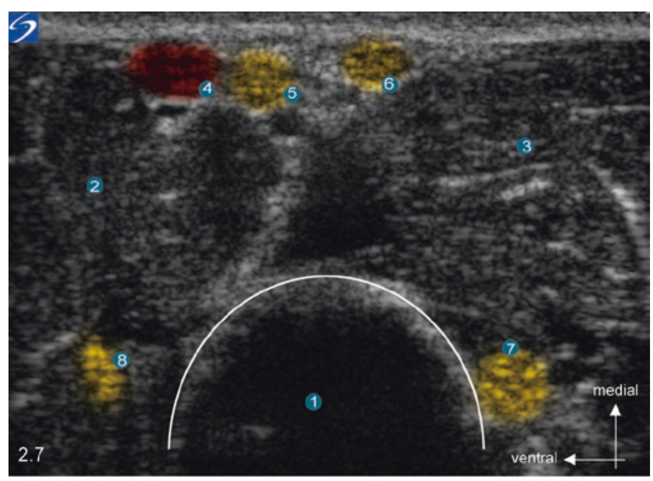


Fig. 5.95 Transverse ultrasound section in the brachial canal: needle insertion near the posterior end of the probe, path of needle (in yellow) to reach radial nerve

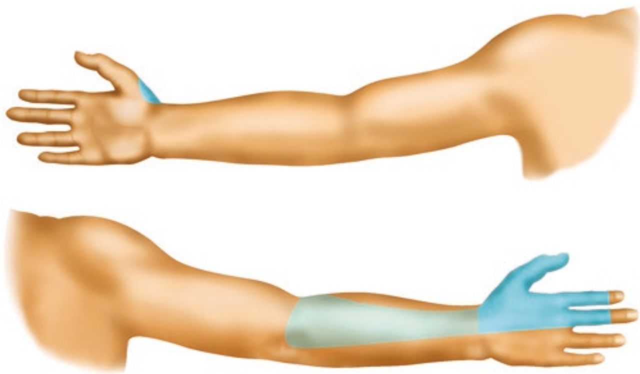


Fig. 5.96 Area of coverage of the truncal blocks of the radial nerve. The lighter blue area shows the innervation by the posterior cutaneous nerve of the forearm

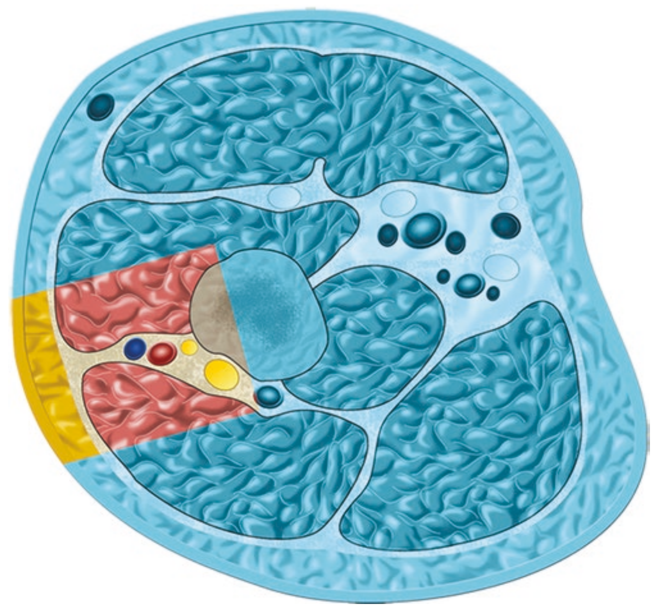


Fig. 5.97 Section of arm at the distal end of the radial groove of the humerus with materialisation of ultrasound beam

Distal Blocks of the Radial Nerve (Fig. 5.96)

Indications

This block can be performed for distal surgery solely in the radial nerve territory or to supplement a proximal brachial plexus block. It is also possible to insert a radial perineural catheter to prolong post-operative analgesia in this area.

Type of probe: linear, 5–10 or 6–13 MHz.
Axis of probe: transversal (Figs. 5.97 and 5.98).
Configuration: nerve in the short axis, needle in or out of plane.
Depth studied: 2–4 cm.
Neurostimulation: enables further identification of the nerves visualised and can limit, by determination of an MIS >0.3 mA (0.1 ms), the risk of accidental intrafascicular injection. Furthermore, it can supplement locating nerves when conditions of visibility are unfavourable.
Needle: 50 or 80 mm isolated, 22 G.
Utility of Doppler ultrasound: deep brachial artery and veins.

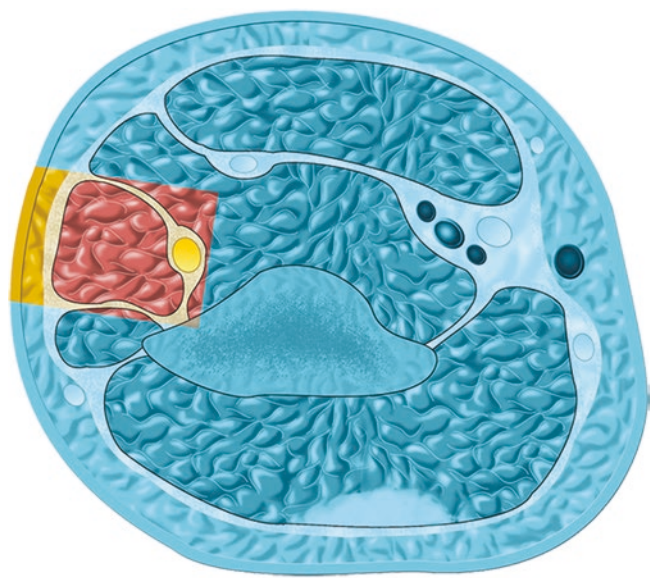
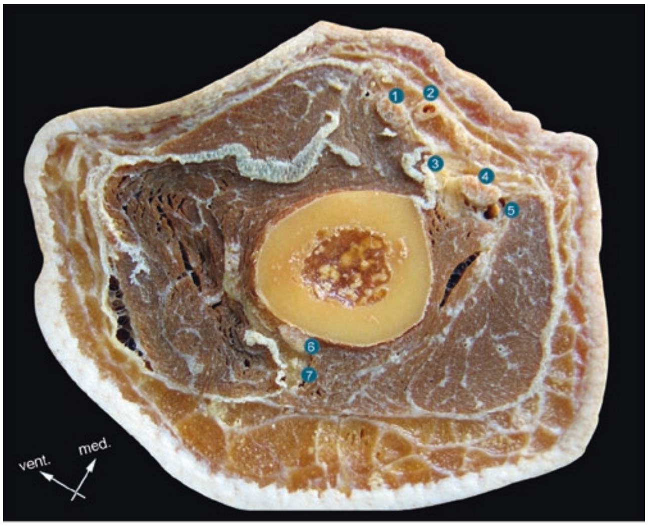


Fig. 5.98 Section in ¼ distal portion of the arm with materialisation of ultrasound beam for performance of a truncal block of the radial nerve

Echoanatomy

At the emergence from the radial groove of the humerus, the neurovascular bundle distances itself from the diaphysis by continuing in the intermuscular space which makes its visibility especially favourable with ultrasound. It consists of the posterior cutaneous nerve of the forearm (PCFA), the terminal branch of the radial nerve and the deep vessels of the arm. Separation of the PCFA often is easy to demonstrate (Figs. 5.99 and 5.100). This is not the case when a more distal approach (from 2 to 3 cm above the flexion point of the elbow) where the PCFA risks not being blocked by the local anaesthetic due to insufficient cephalic spread.



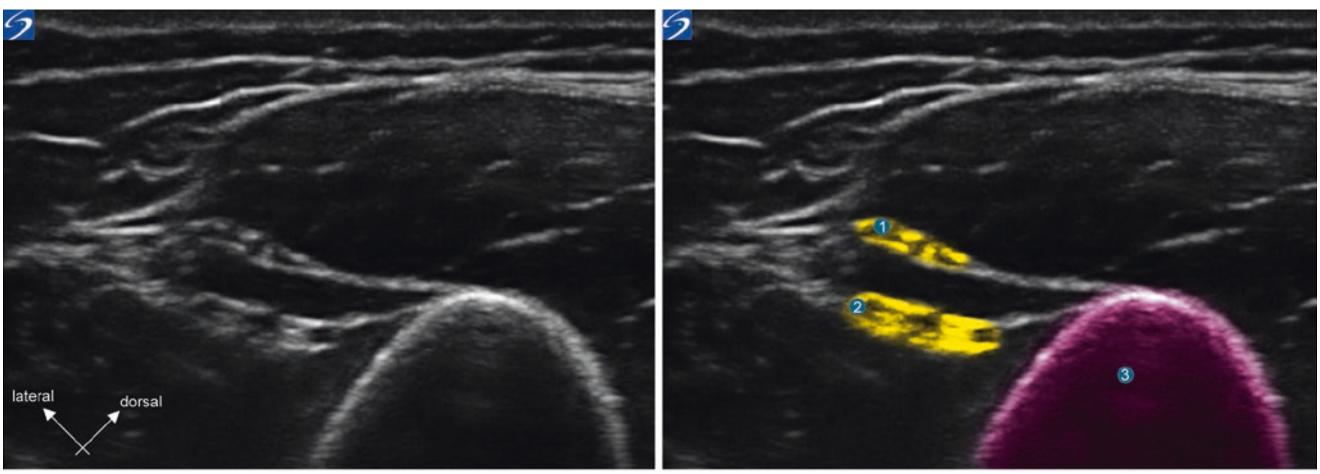
1. median n. 2. brachial a.
3. medial intermuscular septum 4. ulnar n.
5. superior ulnar collateral a. 6. radial n.
7. posterior antebrachial cutaneous n.

Fig. 5.99 Anatomical section in the distal end of radial groove of the humerus

Localisation and Injection

The probe is positioned transversely to the path of the radial nerve.

1. **If injection of local anaesthetic is performed at the emergence of the radial groove**, anaesthesia is obtained in the entire territory of the radial nerve below the elbow. The patient's upper limb and the probe are positioned as in Fig. 5.101. The underlaying anatomy (Fig. 5.99) is well demonstrated by ultrasound (Fig. 5.100). The needle is inserted in-plane at the anterior end of the probe. It passes between the brachialis muscle and the lateral head of the triceps brachialis muscle up to the nerve bifurcation at the emergence from the radial groove (Fig. 5.102) where 5–7 mL of local anaesthetic are sufficient to ensure anaesthesia of both components of the nerve (radial and PCFA). (By turning the ultrasound probe in the long axis of the radial nerve, a longitudinal section is obtained where the bifurcation of the radial nerve and of its PCFA branch are seen (Fig. 5.103). This image is relatively difficult to stabilise and is shown for interest only.)



1. posterior antebrachial cutaneous n. 2. radial n. 3. humerus

Fig. 5.100 Truncal block of the radial nerve. Echoanatomy at distal emergence of radial groove of the humerus: separation of the posterior cutaneous nerve of the forearm

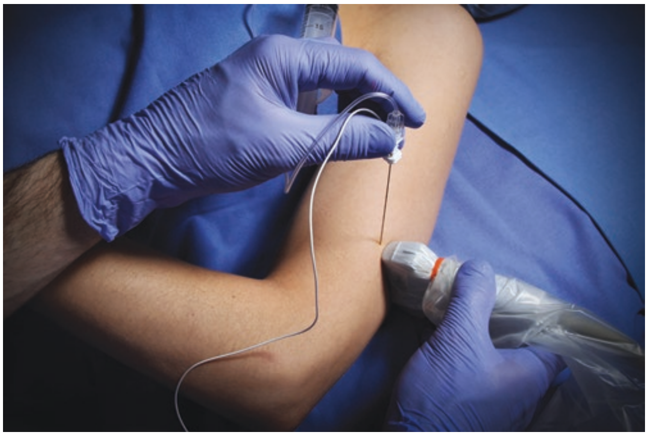


Fig. 5.101 Truncal block of radial nerve at level of its emergence from the radial groove of humerus

2. **If it is chosen to inject the local anaesthetic above the point of flexion of the elbow (the traditional technique with neurostimulation)**, the probe should be placed as in Fig. 5.104. The anaesthetised area then is, at least, that of the superficial and deep branches of the radial nerve that are visualised with ultrasound (Fig. 5.105), which correlates well with the underlying anatomy (Fig. 5.106).

Anaesthesia in the area of the PCFA (Fig. 5.96) is inconsistent with this approach. In fact, the latter is already located at a distance, following in the subcutaneous tissue of the lateral epicondyle-olecranon groove. It is necessary to rely on sufficient cephalic spread of the local anaesthetic to reach it at the level of bifurcation, which

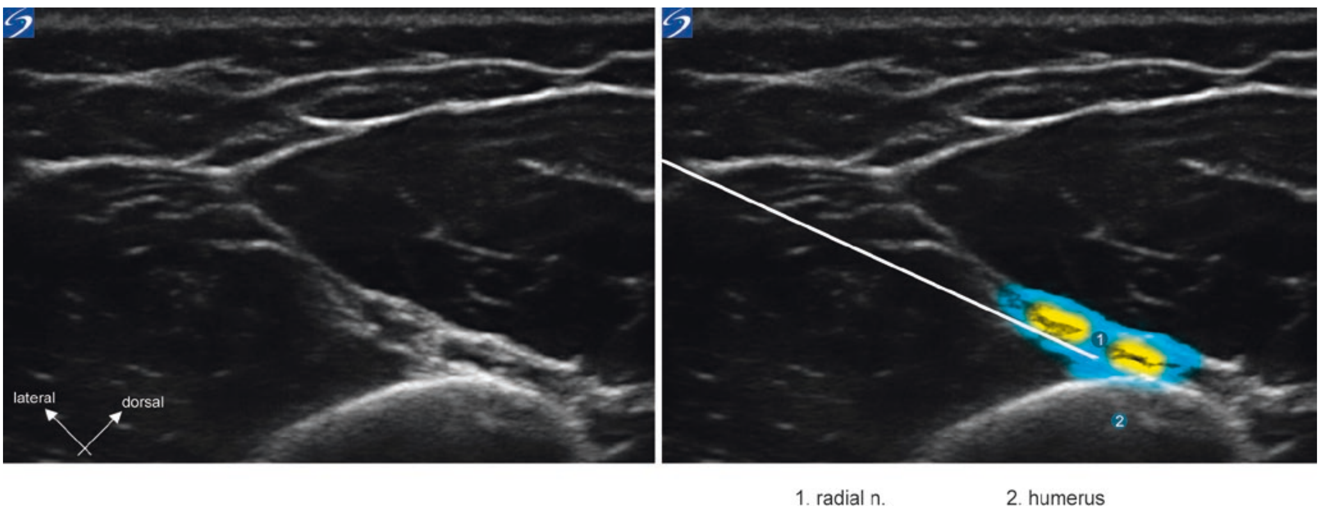


Fig. 5.102 Truncal block of radial nerve at level of its emergence from the radial groove of humerus: transverse section

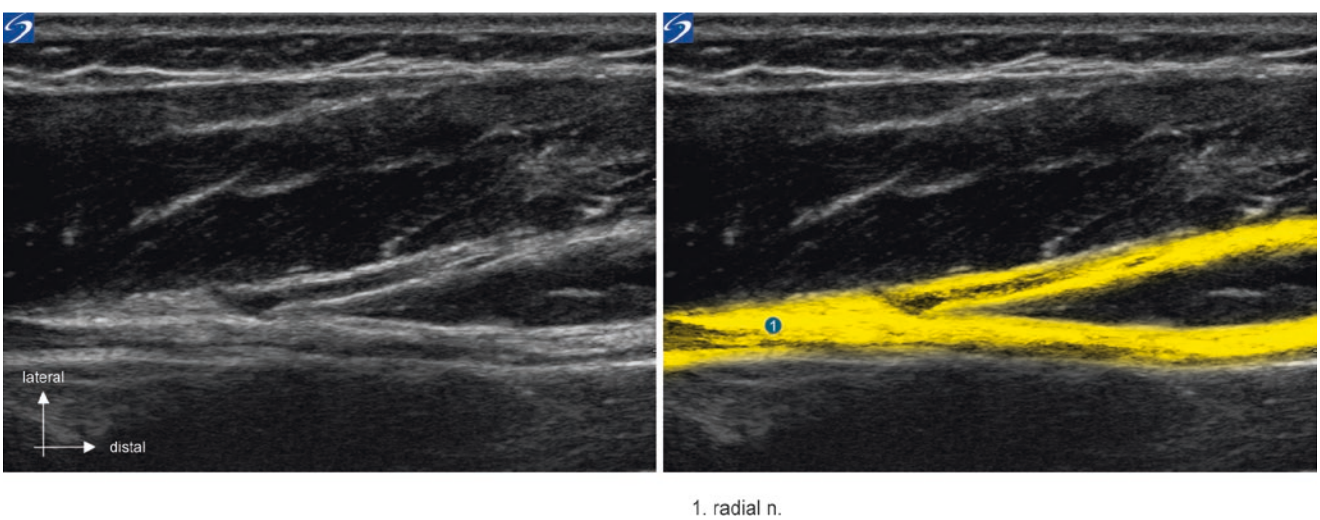
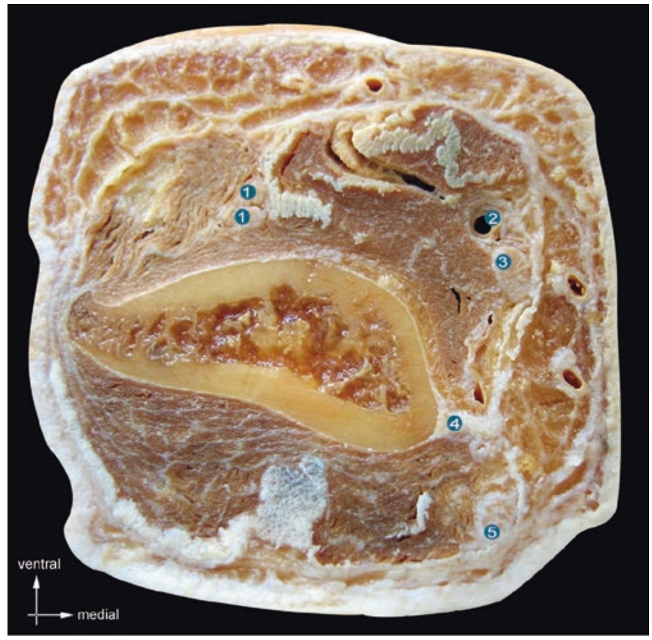


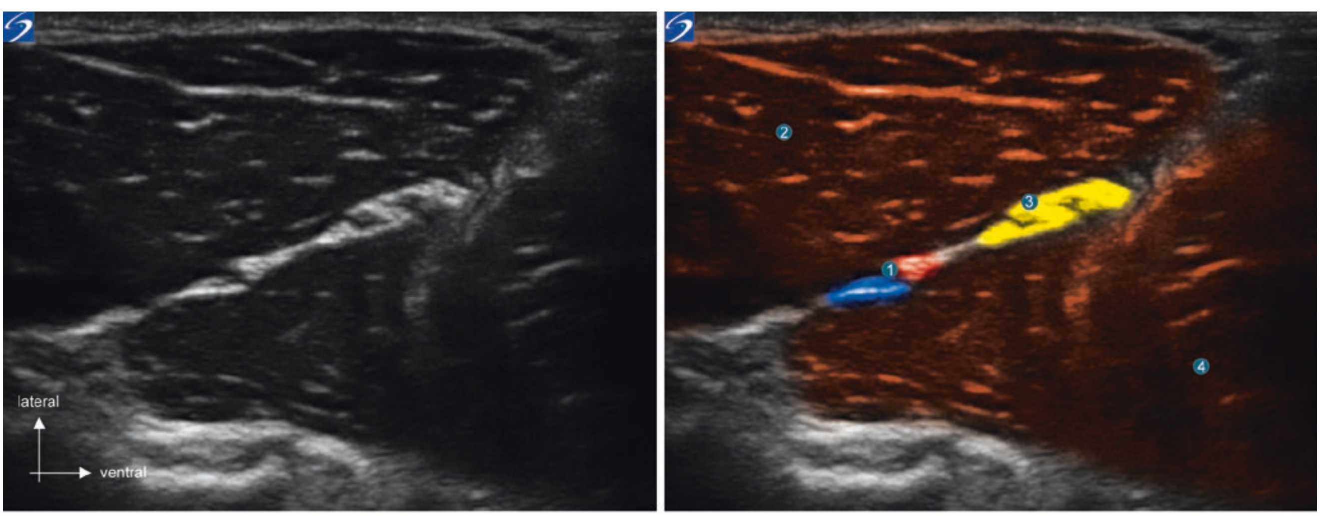
Fig. 5.103 Truncal block of radial nerve at level of its emergence from the radial groove of humerus: longitudinal section showing the posterior cutaneous nerve of the forearm separating from the radial nerve

Fig. 5.104 Truncal block of radial nerve at the elbow: position of the ultrasound probe



1. radial n. (superficial and deep branches)
2. brachial a.
3. median n.
4. medial intermuscular septum
5. ulnar n.

Fig. 5.106 Anatomical section in ¼ distal portion of the arm



1. radial recurrent a. and v.
2. brachioradialis m.
3. superficial and deep branches of radial n.
4. brachialis m.

Fig. 5.105 Truncal block of radial nerve at the elbow: transverse section visualising superficial and deep branches of radial nerve

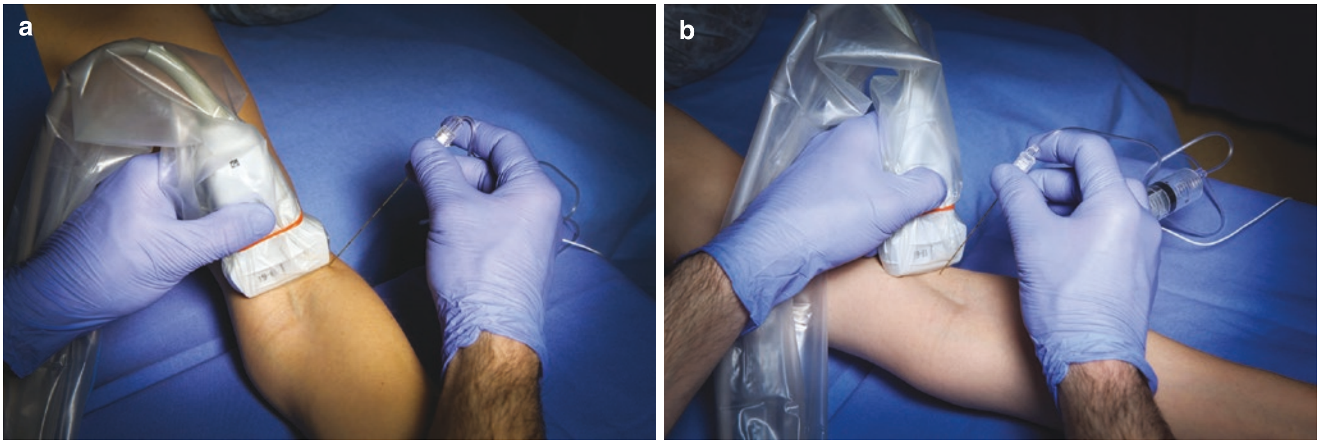


Fig. 5.107 Truncal block of radial nerve at the elbow. (**a**) In-plane. (**b**) Out-of-plane

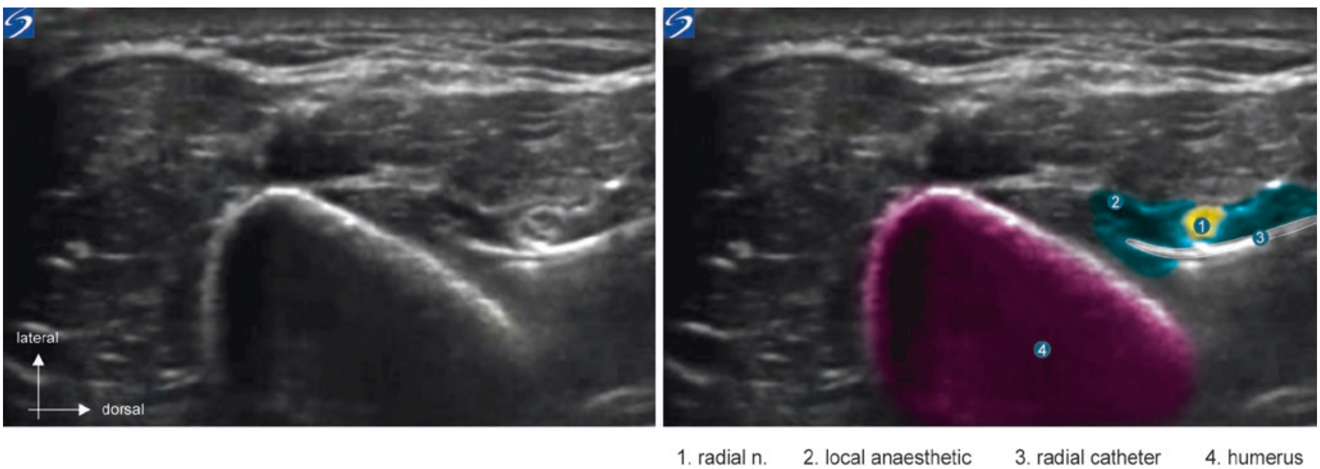


Fig. 5.108 Continuous block of radial nerve: catheter placed in-plane at the emergence from the radial groove of humerus. (Iconography: Nicolas Dufeu)

may not occur with a conventional volume of LA. A block can be performed either in-plane (Fig. 5.107a), or out-of-plane with the aid of the hydrolocalization process (Fig. 5.107b). Five to 7 mL are sufficient to ensure effective anaesthesia.

Figure 5.108 shows a catheter positioned in-plane at the emergence of the radial groove of the humerus.

Distal Blocks of the Median Nerve (Fig. 5.109)

Indications

This block can be performed for distal surgery solely in the median nerve territory or to supplement a proximal brachial plexus block.

Type of probe: linear, 5–10 or 6–13 MHz.
Axis of the probe: transversal (Fig. 5.110).
Configuration: nerve in short axis, needle in or out of plane.
Studied depth: 1–4 cm.
Neurostimulation: enables further identification of the nerves visualised and can limit, by determination of an MIS >0.3 mA (0.1 ms), the risk of accidental intrafascicular injection. Furthermore, it can supplement locating nerves when conditions of visibility are unfavourable.
Needle: 50 or 80 mm isolated, 22 G.
Utility of Doppler ultrasound: brachial artery and veins, superior ulnar collateral artery.

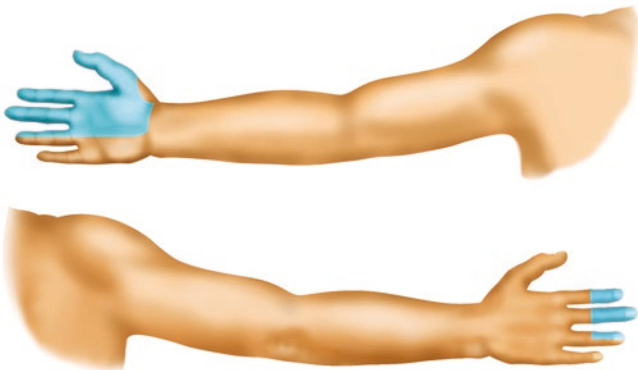


Fig. 5.109 Area of coverage of a truncal block of the median nerve

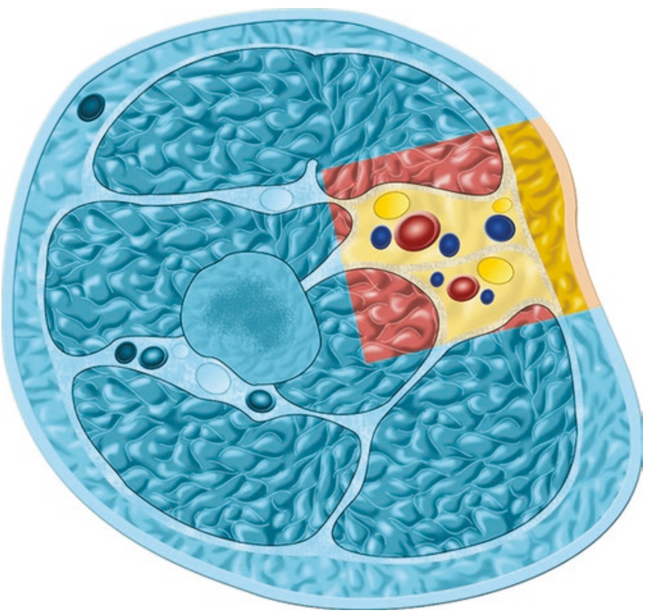
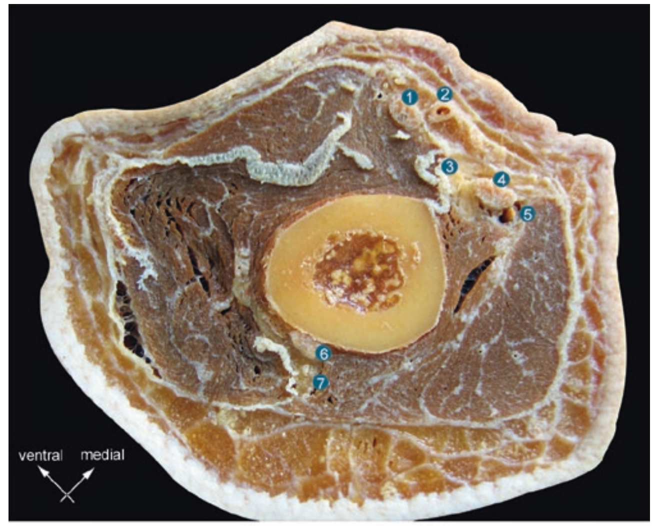
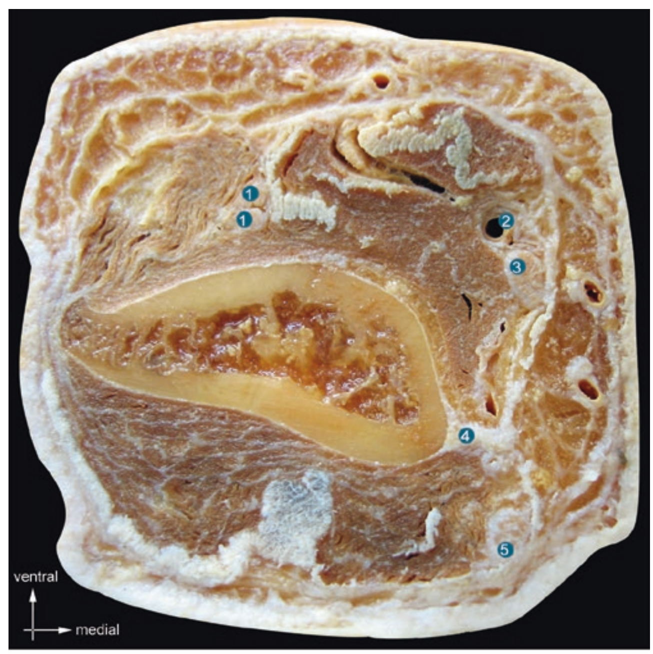


Fig. 5.110 Section of the arm at the middle third-distal third junction of the arm with materialisation of ultrasound beam



1. median n. 2. brachial a. 3. medial septum
4. ulnar n. 5. superior ulnar collateral a.
6. radial n. 7. posterior antebrachial cutaneous n.

Fig. 5.111 Anatomical section at level of the distal end of the radial groove of humerus



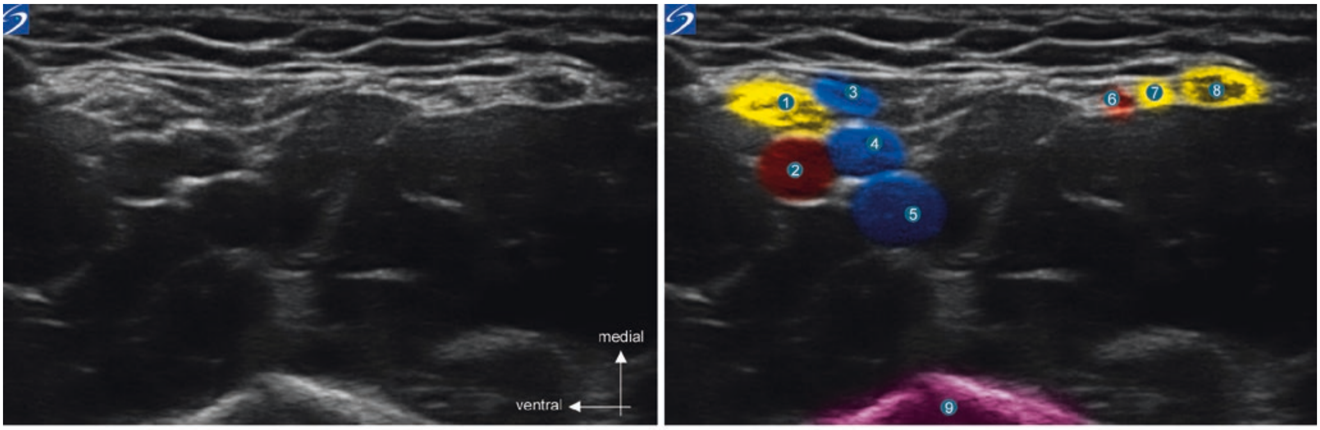
1. radial n. (superficial and deep branches)
2. brachial a. 3. median n.
4. medial intermuscular septum 5. ulnar n.

Fig. 5.112 Anatomical section at the distal quarter of arm

Echoanatomy

At the distal end of the arm, the median nerve is located in immediate proximity to the brachial artery and veins (Figs. 5.111 and 5.112), in front of the medial brachial intermuscular septum. Ultrasound makes it possible to easily visualise these neurovascular structures (Fig. 5.113). At this level, a simple and superficial approach makes it possible to perform, if necessary, a combined block of the median and ulnar nerves with a single injection site with a single redirection of the needle, or by a separate approach when they are relatively distant from each other.

At the end of its path in the anterior compartment of the forearm, the median nerve becomes superficial and a few centimetres above the wrist it is positioned deep to the tendons of the flexor carpi radialis muscle laterally, and the palmar longus muscle medially (Figs. 5.114 and 5.115). Lying superficial to the deep flexors, the long flexor of the thumb and the pronator teres muscle, the median nerve is differentiated from the adjacent tendons by its anisotropic characteristics and its mobility during flexion of the fingers. Identification of the median nerve is facilitated by the so-called "elevator" technique, which consists of following it from a more proximal level where its identification is more certain.

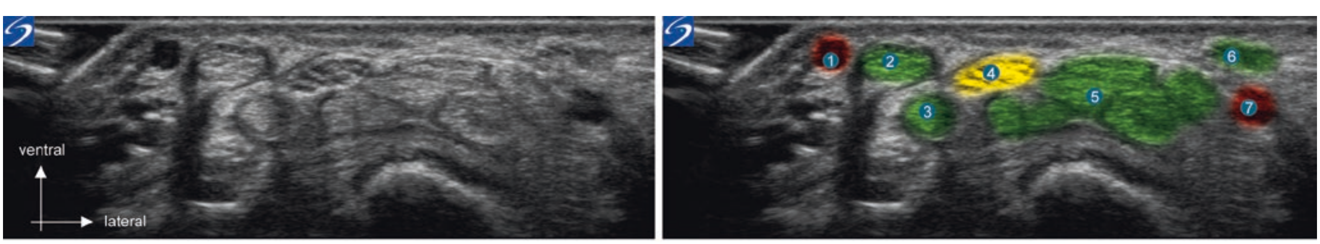


1. median n. 2. brachial a. 3. basilic v.
4. brachial v. 5. brachial v. 6. superior ulnar collateral a.
7. medial antebrachial cutaneous n. 8. ulnar n. 9. humerus

Fig. 5.113 Transverse ultrasound section at middle third-distal third junction of the arm

Fig. 5.114 Distal anatomical section of the forearm cutting through the radioulnar joint

1. flexor carpi radialis tendon 2. palmaris longus tendon
3. median n. 4. flexor pollicis longus tendon
5. radial a.



1. radial a. 2. flexor carpi radialis tendon
3. flexor pollicis longus tendon 4. median n.
5. flexor digitorum profundus tendon 6. flexor carpi ulnaris tendon
7. ulnar a.

Fig. 5.115 Transverse ultrasound section: median nerve at the wrist

Fig. 5.116 Truncal block of the median nerve at the middle third-distal third junction of the arm. Needle inserted in-plane

Fig. 5.117 Truncal block of median nerve at the middle third-distal third junction of arm. Needle inserted out-of-plane

Localisation and Injection

Above the Elbow Joint

The probe is positioned transversely, in the medial aspect of the inferior end of the arm, at a level where visualisation of the target structures is optimum (Fig. 5.116). The neurovascular structures are seen in their short axis (transversal section) (Fig. 5.110). The needle is introduced in-plane at the anterior extremity of the probe (Fig. 5.116). However, the nerve can be approached out-of-plane using hydrolocalisation to visualise the needle tip (Fig. 5.117). Note that the nerve lies in a very shallow position and this approach could risk accidental nerve puncture if the needle tip is not quickly visualised. At this level, a simple redirection of the needle also makes it possible to perform anaesthesia of the ulnar nerve.

Forearm

The probe is placed transversely between 5 and 8 cm above the point of flexion of the wrist according to the quality of visualisation of the median nerve (Figs. 5.118 and 5.119). This position ensures a block of the palmar cutaneous branch

Fig. 5.118 Truncal block of median nerve at the forearm. Needle inserted out-of-plane

of the median nerve prior to its emergence. The existence of numerous muscles and tendons in the anterior compartment of the forearm at this distal site promotes the use of an out-of-plane approach, combined with a hydrolocalisation technique to identify the needle tip during its insertion. The needle is advanced between the tendons of the palmar longus and flexor carpi radialis muscles and placed next to the nerve. However, an in-plane approach may be preferred by targeting the median nerve from the lateral side (the motor nerves of the thenar branch which are located on the lateral side of the nerve would be more accessible to neurostimulation). Five to 7 mL of local anaesthetic are sufficient to obtain anaesthesia.

Distal Blocks of the Ulnar Nerve (Fig. 5.120)

Indications

This block can be performed for distal surgery solely in the ulnar nerve territory or to supplement a proximal brachial plexus block.

Type of probe: linear, 5–10 or 6–13 MHz.
Axis of probe: transversal (Fig. 5.121).
Configuration: nerve in short axis, needle in or out of plane.
Depth studied: 1–4 cm.
Neurostimulation: enables further identification of the nerves visualised and can limit, by determination of an MIS >0.3 mA (0.1 ms), the risk of accidental intrafascicular injection. Furthermore, it can supplement locating nerves when conditions of visibility are unfavourable.
Needle: 50 or 80 mm isolated, 22 G.
Utility of Doppler ultrasound: brachial artery and veins and upper ulnar collateral artery for approach in the arm; ulnar artery for approach in the lower third of the forearm.

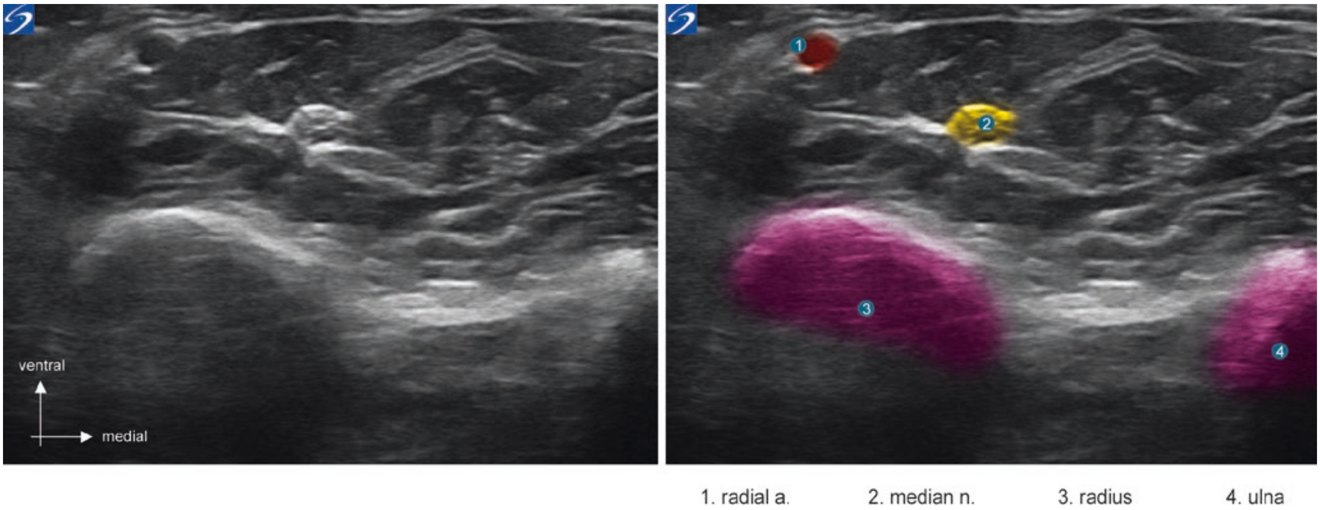


Fig. 5.119 Transverse ultrasound section in the distal third of the forearm

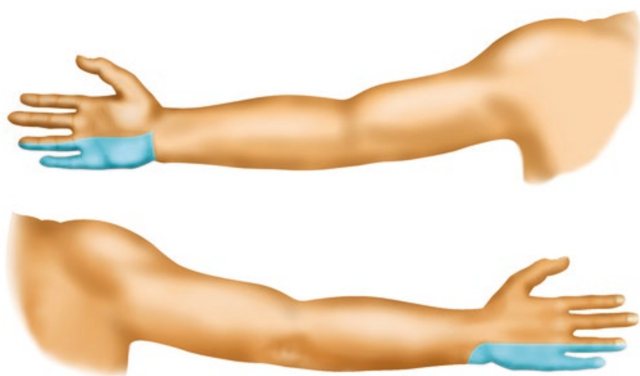


Fig. 5.120 Area of coverage of a truncal block of the ulnar nerve

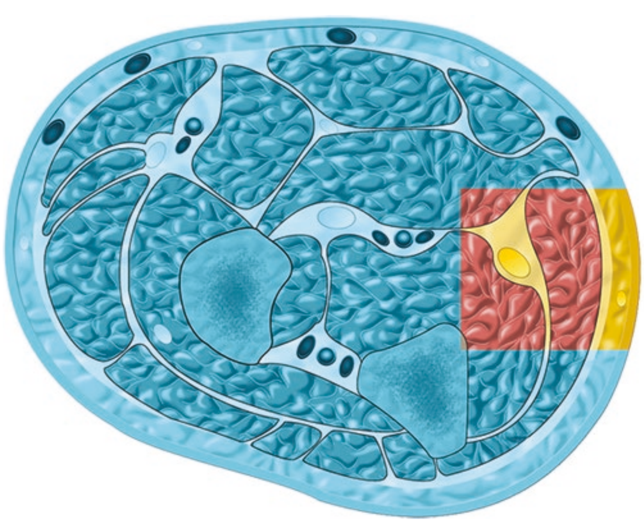


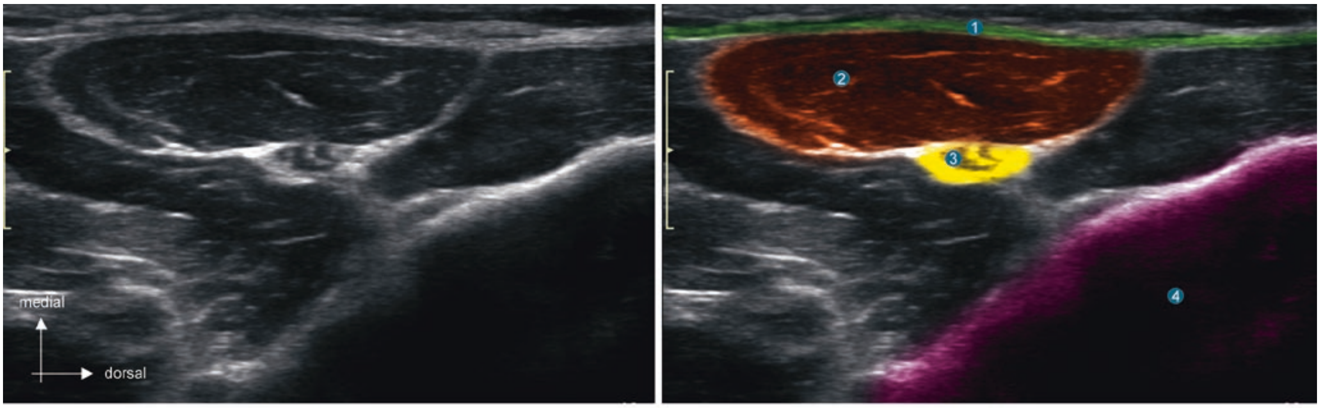
Fig. 5.121 Materialisation of ultrasound beam for block of ulnar nerve in the proximal aspect of the forearm

Fig. 5.122 Ulnar truncal block in the distal third of the arm. Needle inserted out-of-plane

Echoanatomy and Localization

In the distal third of the arm, the ulnar nerve is easy to locate. It is located immediately deep to the brachialis fascia, in immediate proximity to the upper ulnar collateral artery, behind the medial brachial intermuscular septum. Ultrasound makes it possible to easily locate these neurovascular structures (Fig. 5.113). At this level, a simple and superficial approach makes it possible to perform, if necessary, a combined block of the median and ulnar nerves via a single injection site with a single redirection of the needle (Figs. 5.116 and 5.122). Depending on their relative positions, a separate block of both nerves may be required.

At the elbow, nerve blocks performed in the olecranon groove should be avoided because of its lack of compliance and the potential for risk of traumatic/compressive damage to the ulnar nerve. An approach in the proximal forearm is



1. antebrachial fascia 2. flexor carpi ulnaris m.
3. ulnar n. 4. ulna

Fig. 5.123 Transverse ultrasound section of ulnar nerve in the distal third of the forearm

1. radial a. 2. median n. 3. ulnar a.
4. flexor carpi ulnaris m. 5. ulnar n.

Fig. 5.124 Distal anatomical section of the forearm cutting through radioulnar joint

Fig. 5.125 Ulnar block at the proximal aspect of the forearm. Needle inserted in-plane

preferred after emergence of the nerve from the olecranon groove. In this region the ulnar nerve is easy to locate and approach, located deep to flexor carpi ulnaris muscle (FCU) (Fig. 5.123).

In the distal forearm, the ulnar nerve is easy to locate laterally to the tendon of the FCU (Fig. 5.124), accompanied by the ulnar artery from the middle third of the forearm.

Injection

Ulnar Nerve Block in the Distal Arm

The probe is positioned transversely on the medial aspect of the distal arm, as with block of the median nerve. For an in-plane approach, the needle is inserted at one end of the probe, and advanced until adjacent to the ulnar nerve (Fig. 5.116). However, the nerve can also be approached out-of-plane, with the aid of hydrolocalisation to identify the needle tip during its insertion (Fig. 5.122).

Ulnar Nerve Block in the Proximal Forearm

With the probe positioned tranversely in relation to the nerve axis, the ulnar nerve is located deep to FCU and can be approached in or out of plane (Figs. 5.125 and 5.126).

Ulnar Nerve Block in the Distal Forearm

The probe is placed transversely to the longitudinal axis of the nerve, at the medial border of the distal forearm. Due to the tendon of the FCU muscle lying ventrally (with the ulna lying dorsally), the needle is more easily inserted out-of-plane (Fig. 5.127). The nerve is cautiously approached by performing hydrolocalisation, taking care to not puncture it or the adjacent ulnar blood vessels (Fig. 5.128).

Fig. 5.126 Ulnar block at the proximal aspect of the forearm. Needle inserted out-of-plane

Fig. 5.127 Ulnar block at the distal third of the forearm. Needle inserted out-of-plane

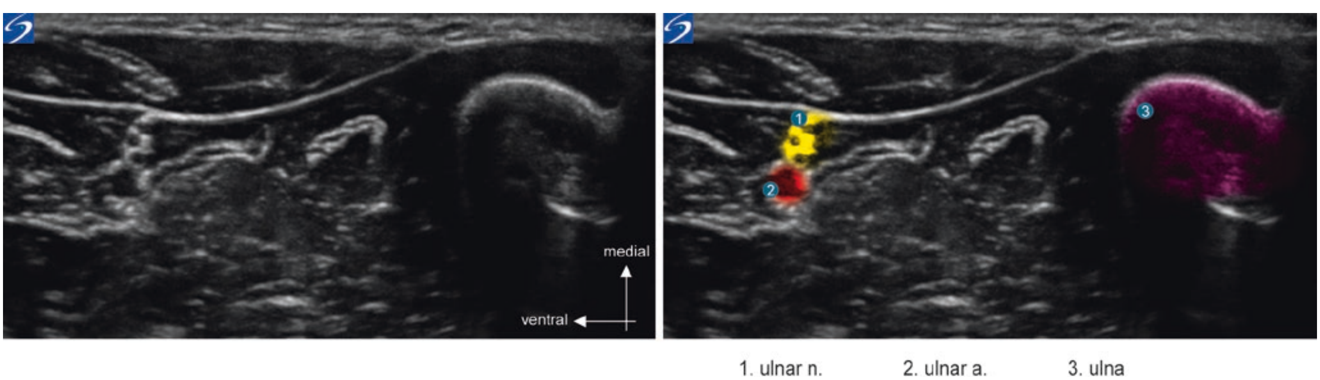


Fig. 5.128 Sonoanatomy. Ulnar nerve at the distal aspect of the forearm

References

1. Kamina P. Précis d'anatomie clinique. Tome 1. Paris: Maloine; 2003.
2. Seddon HJ. Surgical disorders of the peripheral nerves. Édimbourg: Churchill Livingstone; 1972.
3. Borene SC, Edwards JN, Boezaart AP. At the cords, the pinkie towards: interpreting infraclavicular motor response to neurostimulation. Reg Anesth Pain Med. 2004;29:125–9.
4. Lanz E, Theiss D, Jankovic D. The extent of blockade following various techniques of brachial plexus block. Anesth Analg. 1983;62:55–8.
5. Gaertner E, Choquet O, Macaire P, Zetlaoui PJ. Anesthésie régionale, anesthésie tronculaire et plexique de l'adulte. Rueil-Malmaison: Arnette; 2001.
6. Gaertner E, Estebe JP, Zamfir A, Cuby C, Macaire P. Infraclavicular plexus block: multiple injection versus single injection. Reg Anesth Pain Med. 2002;27:590–4.
7. Lavoie J, Martin R, Tetrault JP, Cote DJ, Colas MJ. Axillary plexus block using a peripheral nerve stimulator: single or multiple injections. Can J Anaesth. 1992;39:583–6.
8. Gaertner E, Bouaziz H. Ultrasound-guided interscalene block. Ann Fr Anesth Réanim. 2012;31:e213–8.
9. Nadeau MJ, Lévesque S, Dion N. Ultrasound-guided regional anesthesia for upper limb surgery. Can J Anaesth. 2013;60:304–20.
10. Meier G, Bauereis C, Maurer H. The modified technique of continuous suprascapular nerve block. A safe technique in the treatment of shoulder pain. Anaesthesist. 2002;51:747–53.
11. Vandepitte C, Gautier P, Xu D, Salviz EA, et al. Effective volume of ropivacaine 0.75% through a catheter required for interscalene brachial plexus blockade. Anesthesiology. 2013;118:863–7.
12. Falcão LF, Perez MV, de Castro I, et al. Minimum effective volume of 0.5% bupivacaine with epinephrine in ultrasound-guided interscalene brachial plexus block. Br J Anaesth. 2013;110:450–5.
13. Madison SJ, Humsi J, Loland VJ, et al. Ultrasound-guided root/trunk (interscalene) block for hand and forearm anesthesia. Reg Anesth Pain Med. 2013;38:226–32.
14. Liu SS, Gordon MA, Shaw PM. A prospective clinical registry of ultrasound-guided regional anesthesia for ambulatory shoulder surgery. Anesth Analg. 2010;111:617–23.
15. Krone SC, Chan VW, Regan J, et al. Analgesic effects of low-dose ropivacaïne for interscalene brachial plexus block for outpatient shoulder surgery: a dose-finding study. Reg Anesth Pain Med. 2001;26:439–43.
16. Fredrickson MJ, Abeysekera A, Price DJ, et al. Patient-initiated mandatory boluses for ambulatory continuous interscalene analgesia: an effective strategy for optimizing analgesia and minimizing side-effects. Br J Anaesth. 2011;106:239–45.
17. Borgeat A, Schappi B, Biasca N, Gerber C. Patient-controlled analgesia after major surgery: patient controlled interscalene analgesia vs patient-controlled analgesia. Anesthesiology. 1997;87:1343–7.
18. Borgeat A, Tewes E, Biasca N, Gerber C. Patient-controlled interscalene analgesia with ropivacaine after major surgery: PCIA vs PCA. Br J Anaesth. 1998;81:603–5.
19. Singelyn FJ, Seguy S, Gouverneur JM. Interscalene brachial plexus analgesia after open shoulder surgery: continuous versus patient-controlled infusion. Anesth Analg. 1999;89:1216–20.
20. Sato S, Yamashita S, Iwai M, Mizuyama K, Satsumae ET. Continuous interscalene block for cancer pain. Reg Anesth Pain Med. 1994;19:385–6.
21. Rawal N, Axelsson K, Hylander J, et al. Post-operative patient-controlled local anesthetic administration at home. Anesth Analg. 1998;86:86–9.
22. Macaire P, Gaertner E, Capdevila X. Continuous post-operative regional analgesia at home. Minerva Anestesiol. 2001;67:109–16.
23. Nielsen KC, Greengrass RA, Pietrobon R, Klein SM, Steele SM. Continuous interscalene brachial plexus blockade provides good analgesia at home after major shoulder surgery. Report of four cases. Can J Anaesth. 2003;50:57–61.
24. Ilfeld BM, Enneking FK. A portable mechanical pump providing over four days of patient-controlled analgesia by perineural infusion at home. Reg Anesth Pain Med. 2002;27:100–4.
25. Martinoli C, Bianchi S, Santacroce E, Pugliese F, Graif M, Derchi LE. Brachial plexus sonography: a technique for assessing the root level. Am J Roentgenol. 2002;179:699–702.
26. Cash CJ, Sardesai AM, Berman LH, et al. Spatial mapping of the brachial plexus using three-dimensional ultrasound. Br J Radiol. 2005;78:1086–94.
27. Harry WG, Bennett JD, Guha SC. Scalene muscles and the brachial plexus: anatomical variations and their clinical significance. Clin Anat. 1997;10:250–2.
28. Ediale KR, Myung CR, Neuman GG. Prolonged hemidiaphragmatic paralysis following interscalene brachial plexus block. J Clin Anesth. 2004;16:573–5.
29. Bashein G, Robertson HT, Kennedy WF Jr. Persistent phrenic nerve paralysis following interscalene brachial plexus block. Anesthesiology. 1985;63:102–4.
30. Robaux S, Bouaziz H, Boisseau N, Raucoules-Aime M, Laxenaire MC. Persistent phrenic nerve paralysis following interscalene brachial plexus block. Anesthesiology. 2001;95:1519–21.
31. Franco CD, Gloss FJ, Voronov G, Tyler SG, Stojilkovic LS. Supraclavicular block in obese population: an analysis of 2020 blocks. Anesth Analg. 2006;102:1252–4.
32. Kjoscielnak-Nielsen ZJ, Frederiksen BS, Rasmussen H, et al. A comparison of ultrasound-guided supraclavicular and infraclavicular blocks for upper extremity surgery. Acta Anaesthesiol Scand. 2009;53:620–6.
33. Fredrickson MJ, Patel A, Young S, Chinchanwala S. Speed of onset of « corner pocket supraclavicular » and infraclavicular ultrasound guided brachial plexus block: a randomised observer-blinded comparison. Anesthesia. 2009;64:738–44.
34. Moore DC. Complications induced by block techniques. In: Anesthésiques locaux en anesthésie et réanimation. Paris: Arnette; 1973. p. 397–412.
35. Brand L, Papper EM. A comparison of supraclavicular and axillary techniques for brachial plexus block. Anesthesiology. 1961;22:226–9.
36. SFAR. Recommandations pour la pratique clinique. Les blocs nerveux périphériques chez l'adulte. Paris: SFAR; 2003. www.sfar.org.
37. Dupré LJ. Le bloc du plexus brachial par voie sus-claviculaire. www.i-alrf.asso.fr, techniques.
38. Cornish PB, Greenfield LJ, O'Reilly M, Allan L. Indirect versus direct measurement of brachial plexus depth. Anesth Analg. 1999;88:1113–6.
39. Kulenkampff D, Persky A. Brachial plexus anesthesia: its indications, technique and dangers. Ann Surg. 1928;87:883–91.
40. Pauchet V, Sourdat P, Labat G, de Butler d'Ormont R. Anesthésie du plexus brachial. In: Pauchet V, editor. L'anesthésie régionale. Paris: Doin; 1927. p. 146–68.
41. Moore DC. Supraclavicular approach for block of the brachial plexus. In: Moore DC, editor. Regional block: a handbook for use in the clinical practice of medicine and surgery. 4th ed. Springfield, IL: CC Thomas Publisher; 1965. p. 221–42.
42. Dupré LJ, Danel V, Legrand JJ, Stieglitz P. Surface landmarks for supraclavicular block of the brachial plexus. Anesth Analg. 1982;61:28–31.
43. Winnie AP, Collins VJ. The subclavian perivascular technique of brachial plexus anesthesia. Anesthesiology. 1964;25:353–63.
44. Pham-Dang C, Gunst JP, Gouin F, et al. A novel supraclavicular approach to brachial plexus block. Anesth Analg. 1997;85:111–6.

45. Vongvises P, Panijayanond T. A parascalene technique of brachial plexus anesthesia. Anesth Analg. 1979;58:267–73.
46. Brown DL, Cahill DR, Bridenbaugh LD. Supraclavicular nerve block: anatomic analysis of a method to prevent pneumothorax. Anesth Analg. 1993;76:530.
47. Gupta K, Bhandari S, Singhal D, et al. Pneumothorax following ultrasound guided supraclavicular brachial plexus block. J Anaesthesiol Clin Pharmacol. 2012;28:543–4.
48. Sandhu NS, Capan LM. Ultrasound-guided infraclavicular brachial plexus block. Br J Anaesth. 2002;89:254–9.
49. Chan VW, Perlas A, Rawson R, Odukoya O. Ultrasound-guided supraclavicular brachial plexus block. Anesth Analg. 2003;97:1514–7.
50. Kilka HG, Geiger P, Mehrkens HH. Infraclavicular vertical brachial plexus blockade. A new method for anesthesia of the upper extremity. An anatomical and clinical study. Anaesthesist. 1995;44:339–44.
51. Neuburger M, Kaiser H, Ass B, Franke C, Maurer H. Vertical infraclavicular blockade of the brachial plexus (VIP). A modified method to verify the puncture point under consideration of the risk of pneumothorax. Anaesthesist. 2003;52:619–24.
52. Whiffler K. Coracoid block: a safe and easy technique. Br J Anaesth. 1981;53:845–8.
53. Raj PP, Montgomery SJ, Nettles D, Jenkins MT. Infraclavicular brachial plexus block: a new approach. Anesth Analg. 1973;52:897.
54. Sims JK. A modification of landmarks for infraclavicular approach to brachial plexus block. Anesth Analg. 1977;56:554–6.
55. Borgeat A, Ekatodramis G, Dumont C. An evaluation of the infraclavicular block via a modified approach of the Raj technique. Anesth Analg. 2001;93:436–41.
56. Moayeri N, Renes S, van Geffen GJ, Groen GJ. Vertical infraclavicular brachial plexus block: needle redirection after elicitation of elbow flexion. Reg Anesth Pain Med. 2009;34:236–41.
57. Perlas A, Chan VW, Simons M. Brachial plexus examination and localization using ultrasound and electrical stimulation. Anesthesiology. 2003;99:429–35.
58. Bloc S, Garnier T, Komly B, et al. Single-stimulation, low-volume infraclavicular plexus block: influence of the evoked distal motor response on success rate. Reg Anesth Pain Med. 2006;31:433–7.
59. 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.
60. Dalens B. Anesthésie locorégionale de la naissance à l'âge adulte. Paris: Pradel; 1993.
61. Swerdlow M. Complications of local anesthetic neural blockade. In: Cousins MJ, Bridenbaugh P, editors. Neural blockade in clinical anesthesia. Philadelphia: Lippincott; 1980. p. 526–42.
62. Retzl G, Kapral S, Greher M, Mauritz W. Ultrasonographic findings of the axillary part of the brachial plexus. Anesth Analg. 2001;92:1271–5.
63. Chriblockhe JL, Berthier F, Boillot A, et al. Assessment of topographic brachial plexus nerves variations at the axilla using ultrasonography. Br J Anaesth. 2009;103:606–12.
64. Remerand F, Laulan J, Couvret C, et al. Is the musculocutaneous nerve really in the coracobrachialis muscle when performing an axillary block? An ultrasound study. Anesth Analg. 2010;110:1729–34.
65. Testut L. Les anomalies musculaires chez l'homme expliquées par l'anatomie comparée. Leur importance en anthropologie. Paris: Masson; 1884. p. 411.
66. Dalens BJ. Infraclavicular brachial plexus blocks. In: Dalens B, editor. Pediatric regional anesthesia. Boca Raton: CRC Press; 1990. p. 241–55.
67. Coventry DM, Barker KF, Thomson M. Comparison of two neurostimulation techniques for axillary brachial plexus blockade. Br J Anaesth. 2001;86:80–3.
68. Sia S, Lepri A, Ponzecchi P. Axillary brachial plexus block using peripheral nerve stimulator: a comparison between double- and triple-injection techniques. Reg Anesth Pain Med. 2001;26:499–503.
69. Adnan T, Elif A, Ayse A, Gülnaz A. Clonidine as an adjuvant for lidocaine in axillary brachial plexus block in patients with chronic renal failure. Acta Anesthesiol Scand. 2005;49:563–8.
70. Carles M, Pulcini A, Macchi P, Duflos P, Raucoules-Aime M, Grimaud D. An evaluation of the brachial plexus block at the humeral canal using a neurostimulator (1417 patients): the efficacy, safety, and predictive criteria of failure. Anesth Analg. 2001;92:194–8.
71. Gaertner E, Kern O, Mahoudeau G, Freys G, Golfetto T, Calon B. Block of the brachial plexus branches by the humeral route. A prospective study in 503 ambulatory patients. Proposal of a nerve-blocking sequence. Acta Anaesthesiol Scand. 1999;43:609–13.
72. Gaertner E. Pourquoi je fais un bloc au canal huméral. Prat Anesth-Reanim. 2001;5:277–9.
73. Güntz E, Herman P, Delbos A, Sosnowski M. The radial nerve should be blocked before the ulnar nerve during a brachial plexus block at the humeral canal. Can J Anaesth. 2004;51:354–7.