13

Upper Extremity Nerve Blocks

De Q.H. Tran • Shubada Dugani • Juan Francisco Asenjo

Contents

De.Q.H. Tran, MD, FRCPC (✉) • S. Dugani, MBBS, FRCA • J.F. Asenjo, MD
Department of Anesthesia, Montreal General Hospital, McGill University,
1650 Avenue Cedar, D10-144, Montreal, Quebec H3G-1A4, Canada
e-mail: de_tran@hotmail.com

A.D. Kaye et al. (eds.), *Essentials of Regional Anesthesia*,
DOI 10.1007/978-1-4614-1013-3_13,

Introduction

For more than a century, brachial plexus blockade has been an indispensable tool in the regional anesthesiologist's armamentarium. By providing surgical anesthesia and postoperative analgesia to the entire upper limb, it has been intimately linked to advances in orthopedic and ambulatory anesthesia. Furthermore, with the advent of ultrasonography, upper extremity blocks are being rediscovered under a new light. Every month, anesthesia journals report novel methods to anesthetize different parts of the brachial plexus. Navigating this plethora of studies can be a daunting task. This chapter aims to present a concise discussion of approaches and techniques for brachial plexus blockade based on available evidence.

Clinical Anatomy of the Brachial Plexus

The brachial plexus (Fig. 13.1) is derived from the anterior primary rami of the fifth, sixth, seventh, and eighth cervical nerves as well as the first thoracic nerve in about 75% of the individuals, with variable contributions from the fourth cervical nerve in 15–62% of cases ("prefixed" brachial plexus) and the second thoracic nerve in 16–73% of cases ("postfixed" brachial plexus).

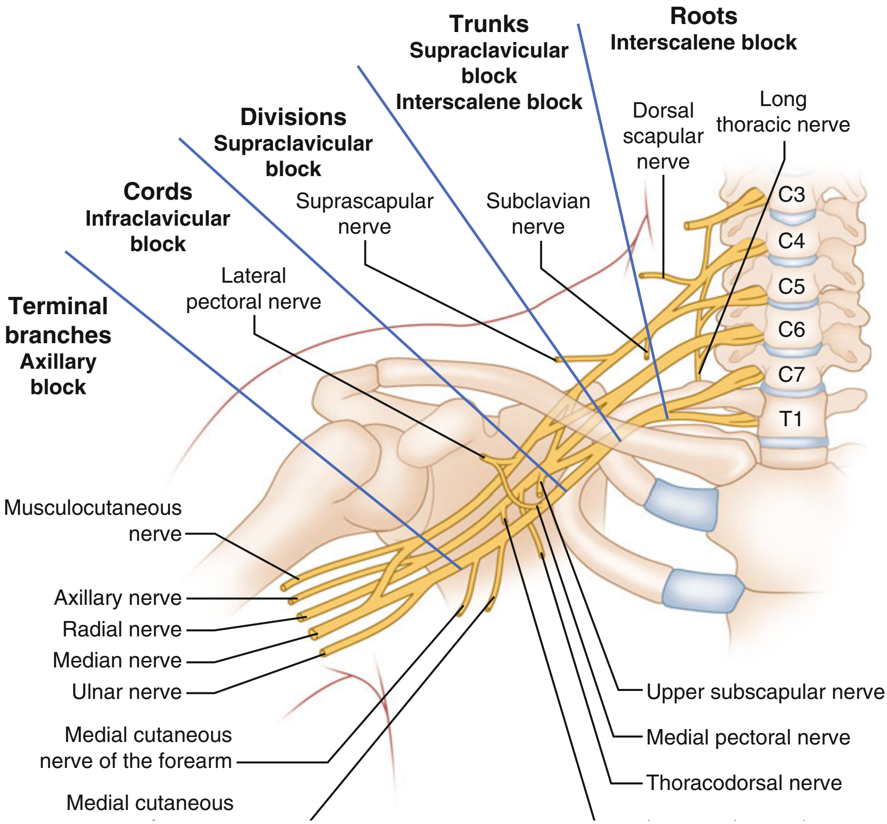

Fig. 13.1 Anatomy of the brachial plexus

The length of the roots, from foramina to trunk, varies between 30 mm (C8 and T1), 40 mm (C5), 50 mm (C6), and 60 mm (C7). The duramater and the epidural connective tissues in the vertebral canal follow the roots to form the perineurium and epineurium, respectively. The roots leave the intervertebral foramina and course between the anterior and middle scalene muscles in the posterior triangle of the neck. Before forming the three trunks (superior, inferior, and middle), the roots give rise to the following nerves:

(a) The long thoracic nerve (C5, C6, and C7), which innervates the anterior serratus muscle, either traverses the middle scalene muscle or exits between the posterior and the middle scalene muscles.
(b) The dorsal scapular nerve (C5), which innervates the rhomboid and levator scapulae muscles, exits behind the middle scalene muscle.
(c) Although the phrenic nerve stems from the C3, C4, and C5 nerves, in 20% of cases, it originates entirely from the roots of the brachial plexus.
(d) The C5, C6, C7, and C8 roots also provide innervation to the scalene and longus colli muscles.

Of the three trunks, the only one giving rise to peripheral branches is the superior trunk. The suprascapular nerve (C5 and C6), which supplies the supra- and infraspinatus muscles, and the nerve to the subclavius muscle (C5 and C6) both originate from the latter.

At the lateral edge of the first rib, each trunk separates into anterior and posterior divisions.

Subsequently, the divisions join to form three cords. The cords are termed lateral (formed from the anterior divisions of the superior and middle trunks, therefore C5 + C6 + C7), posterior (formed from all posterior divisions, C5 + C6 + C7 + C8 + T1), and medial (formed from the anterior divisions of the lower trunk, C8 + T1) based on their relationship with the axillary artery. The cords give rise to multiple side branches:

(a) The lateral pectoral nerve originates from the lateral cord.
(b) The medial pectoral nerve, the medial cutaneous nerve of the arm, and the medial cutaneous nerve of the forearm originate from the medial cord.
(c) The upper subscapular nerve, the lower subscapular nerve, and the thoracodorsal nerve originate from the posterior cord.

At the lateral border of the pectoralis minor muscle, the cords divide into terminal branches: the musculocutaneous nerve (lateral cord), axillary nerve (posterior cord), radial nerve (posterior cord), median nerve (lateral and medial cords), and ulnar nerve (medial cord).

Choosing the Right Approach

Surgery of the Shoulder, Clavicle, and Proximal Humerus

The clavicle and the (posterior) proximal humerus are innervated by the subclavian and suprascapular nerve, respectively (Fig. 13.2). Because they target the latter prior to their take-off from the superior trunk, the cervical paravertebral, interscalene, and supraclavicular approaches can be used.

Although some authors claim that the cervical paravertebral approach differs from its interscalene counterpart because the posterior, and not anterior, cervical roots are anesthetized [1], this remains ambiguous. In the largest randomized controlled trial ($n = 80$) to have compared the two blocks, no differences were found in terms of success rate, extent of the block, as well as onset and offset times [2]. To date, only one study has compared interscalene and supraclavicular blocks. Although block duration, patient satisfaction, postoperative pain scores, and analgesic requirements were similar, the supraclavicular approach resulted in fewer side effects (Horner's syndrome, recurrent laryngeal nerve palsy, and symptomatic diaphragmatic paralysis) [3].

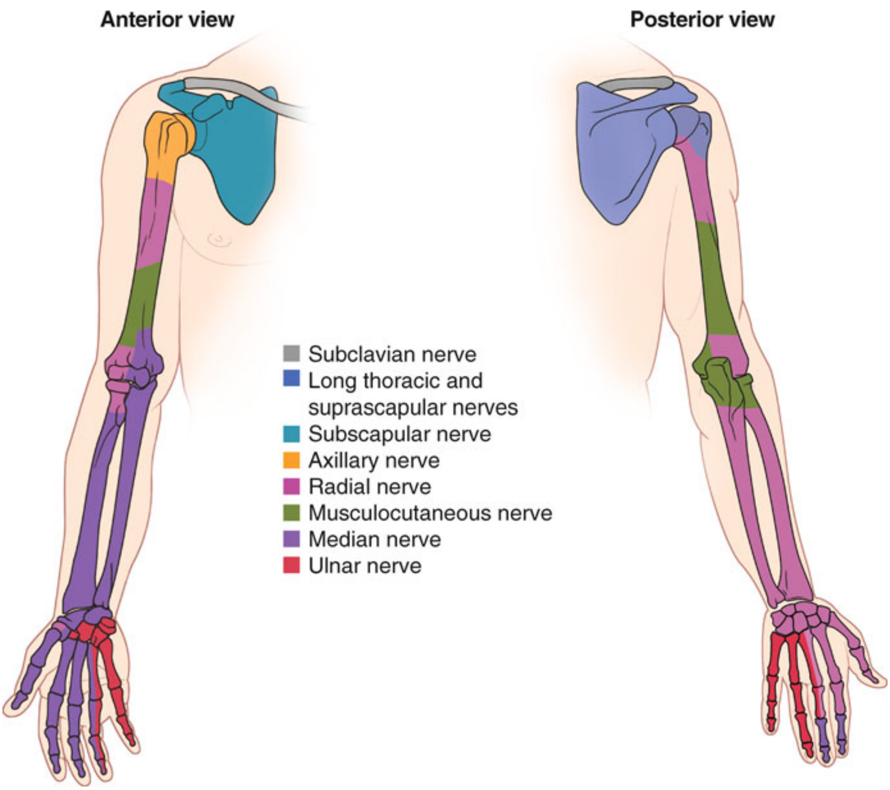

Fig. 13.2 Bony innervation of the upper extremity

Surgery of the Distal Humerus, Forearm, and Hand

The supraclavicular, infraclavicular, and axillary approaches can be used for surgical procedures involving the distal humerus, forearm, and hand. Humeral canal blocks should be reserved for surgery distal to the elbow.

When optimal techniques are utilized for each approach, the literature seems to suggest that supraclavicular, infraclavicular, axillary, and humeral canal blocks result in comparable success rates. As expected, approaches requiring a multiple-injection technique (axillary and humeral canal) can be associated with a longer performance time, more needle passes, or higher block-related pain scores [4–7].

Interscalene Brachial Plexus Block

The Evidence

The interscalene approach anesthetizes the brachial plexus at the level of the roots and trunks. Identification of the plexus in the interscalene groove can be achieved with elicitation of paresthesia, nerve stimulation, or ultrasonography.

To date, three trials have compared elicitation of paresthesia and neurostimulation with mixed results. In two studies, no differences were found [8, 9]. In contrast, the third trial recorded higher failure rates (10 vs. 0%) and postoperative pain scores in the paresthesia group [10].

Comparison of neurostimulation and ultrasonography has also yielded contradictory results. In one study, echoguidance improved the rate of surgical anesthesia (98.8% vs. 91.3%) as well as the onset and offset times [11]. In contrast, another trial observed no differences in performance time, surgical anesthesia, and postoperative neural deficits. However, patients in the ultrasound group required fewer passes [12].

The Techniques

Nerve Stimulation

The patient is supine with the head turned toward the contralateral side. At the level of the cricoid cartilage, posterior to the sternocleidomastoid muscle, the neck is palpated to identify the groove between the anterior and middle scalene muscles (Fig. 13.3).

The skin is infiltrated with local anesthesia. Because the plexus is very superficial, a small volume (<0.3 ml) should be used; otherwise, the evoked motor response may be abolished. A 2.5-cm block needle, connected to a nerve stimulator set at a current of 1.5 mA, a pulse width of 0.1 ms, and a frequency of 2 Hz, is inserted in the interscalene groove. The needle is oriented in a slight caudad direction to avoid penetration of the intervertebral foramen. Typically, contraction of the deltoid, biceps, triceps, or pectoral muscles is seen. All four constitute acceptable evoked motor responses. If diaphragmatic contraction is encountered, the needle tip is close to the phrenic nerve (situated on the anterior scalene muscle) and thus should be redirected posteriorly. Conversely, if the needle is too posterior, stimulation of the dorsal scapular nerve and shoulder elevation (contraction of the rhomboid and levator scapulae muscles) will occur. After ensuring that the evoked motor response is still present at a current of 0.2–0.5 mA, 20–30 ml of local anesthetic are injected.

Ultrasound Guidance

The patient is placed in a supine or semisitting position with the head turned toward the contralateral side. At the level of the cricoid cartilage, the neck is scanned with

Fig. 13.3 Landmarks for interscalene brachial plexus block (*IS* interscalene, *SCM* sternocleido-mastoid muscle, *X* puncture site)

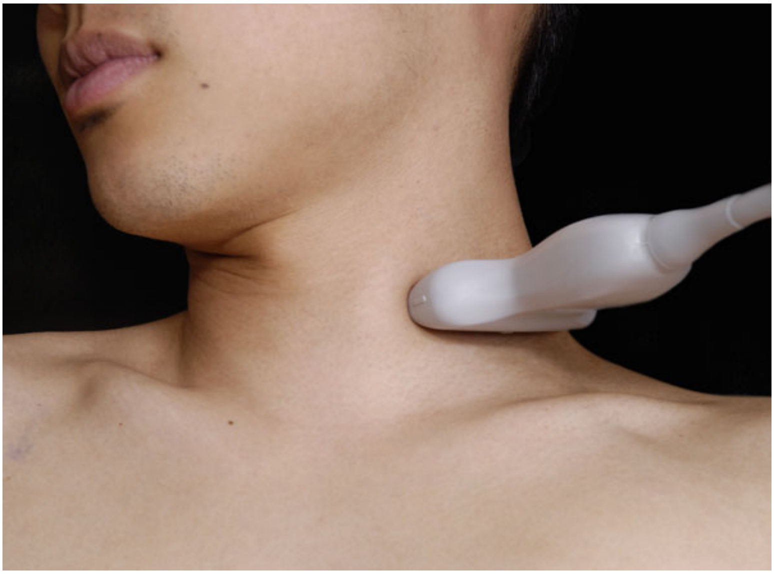

Fig. 13.4 Position of the ultrasound probe for interscalene brachial plexus block

a high-frequency probe (Fig. 13.4). The brachial plexus appears as a column of hypoechoic nodules. The exact nature of the latter (roots vs. trunks) remains controversial (Fig. 13.5). Using an in-plane technique and a lateral to medial direction, the skin and subcutaneous tissues are infiltrated with local anesthesia.

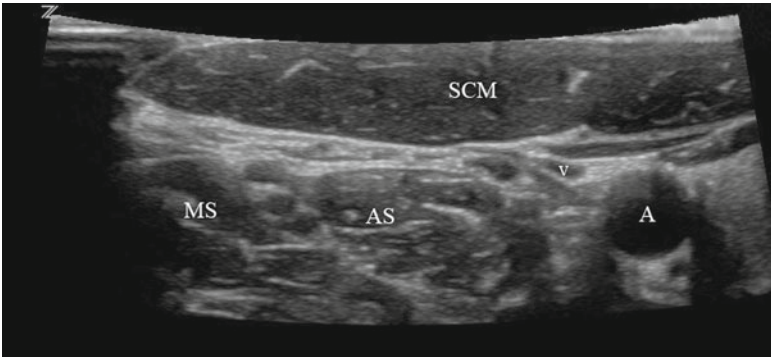

Fig. 13.5 Ultrasonographic appearance of the interscalene and cervical paravertebral brachial plexus (*A* carotid artery, *AS* anterior scalene muscle, *MS* middle scalene muscle, *SCM* sternocleidomastoid muscle, *V* internal jugular vein)

A 5-cm block needle is then inserted. Care must be taken to visualize the entire length of the needle during the advancement process. The classic target for this block is situated between the first and second or second and third nodules. However, an injection in the middle scalene muscle, next to the interscalene groove but without penetration of the latter, seems to provide a similar efficacy [13]. A volume of 20–30 ml of local anesthetic is commonly used.

Complications

Due to the proximity of the cervical sympathetic chain and the recurrent laryngeal nerve, Horner's syndrome and hoarseness can occur. With appropriate technique and equipment, some complications can be prevented: a slight caudad orientation of the needle will decrease the risk of dural cuff puncture and vertebral artery or neuraxial injection. Similarly, limiting the length of needle insertion can prevent the occurrence of a pneumothorax. The most vexing side effect remains the 100% incidence of ipsilateral hemidiaphragmatic paralysis caused by migration of local anesthetics to the C3–5 roots or the phrenic nerve [14]. Usually well tolerated by healthy subjects, it becomes a prohibitive risk in patients with pulmonary compromise. To date, no preventive measure has been found. For instance, a reduction in local anesthetic volume (from 45 to 20 ml) and digital pressure above the injection site did not reduce phrenic paralysis [15–18]. Although 10 ml of bupivacaine 0.25% was not associated with changes in pulmonary function in healthy volunteers [19], a recent study reported a 45% incidence of diaphragmatic paralysis despite limiting the dose of local anesthetic to 5 ml of ropivacaine 0.5% [20].

Cervical Paravertebral Brachial Plexus Block

The Evidence

The cervical paravertebral approach anesthetizes the brachial plexus at the level of the roots and proximal trunks. Identification of the plexus can be carried out with loss of resistance, nerve stimulation, or ultrasonography. To date, no study has compared these three modalities. Most clinicians seem to prefer the latter two.

The Techniques

Nerve Stimulation

The patient is placed in a sitting or lateral decubitus position with the surgical side uppermost. The neck is flexed to facilitate palpation of the C6 and C7 spinous processes. Three to four centimeters lateral to the latter, a paravertebral line is traced in a cephalocaudal axis. This often corresponds to the groove between the levator scapulae and trapezius muscles. The puncture site is located on the midpoint of this paravertebral line (Fig. 13.6).

The skin and subcutaneous tissues are infiltrated with local anesthesia. A 10-cm block needle, connected to a nerve stimulator set at a current of 1.5 mA, a pulse

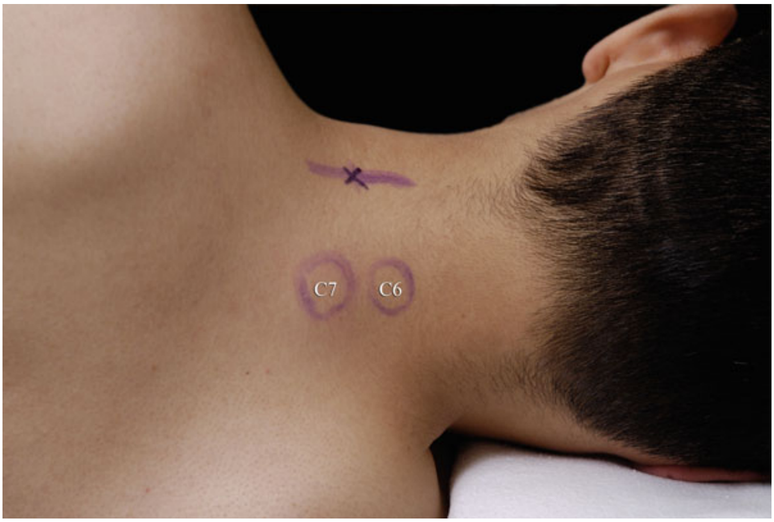

Fig. 13.6 Landmarks for cervical paravertebral brachial plexus block (*X* puncture site)

Fig. 13.7 Position of the ultrasound probe for cervical paravertebral brachial plexus block

width of 0.1 ms, and a frequency of 2 Hz, is inserted perpendicularly to the skin until contact with the pars intervertebralis or transverse process. It is then walked laterally off the bone and advanced until contraction of the deltoid, biceps, triceps, or pectoral muscles is seen. After ensuring that the evoked motor response is still present at a current of 0.2–0.5 mA, 20–30 ml of local anesthetic are injected.

Ultrasonography

The patient is placed in a lateral decubitus position with the surgical side uppermost. At the level of the cricoid cartilage, the neck is scanned with a high-frequency probe to identify the carotid artery (Fig. 13.7). The probe is moved laterally until the interscalene groove can be identified. The brachial plexus appears as a column of hypoechoic nodules (Fig. 13.5). The puncture site for this block is situated in the groove between the levator scapulae and trapezius muscles. The skin and subcutaneous tissues are infiltrated with local anesthesia. Using an in-plane needle, a 10-cm block needle is directed toward the brachial plexus. Care must be taken to visualize the entire length of the needle during the advancement process. The target for this block can be the plexus itself (between the hypoechoic nodules) or the middle scalene muscle, next to the interscalene groove but without penetration of the latter. A volume of 20–30 ml of local anesthetic is commonly used.

Complications

Adverse events related to the cervical paravertebral approach are similar to those associated with interscalene blocks (Horner's syndrome, hoarseness, vascular breach, and hemidiaphragmatic paralysis). Two potential complications deserve special mention. Because the needle traverses the extensor muscles of the neck, muscular pain can be problematic; inserting the needle in the groove between the levator scapulae and trapezius muscles may decrease the incidence of neck pain. Neuraxial spread of local anesthetic agents can occur in up to 4% of cervical paravertebral blocks [21]. To minimize this risk, some authors recommend avoiding sharp needles, which can pierce the dural cuffs. The vertebral artery is situated anterior to the pars intervertebralis or articular column of the vertebrae. Therefore, the vertebral artery should be protected from puncture if the needle is introduced to contact bone and walked laterally off the latter.

Supraclavicular Brachial Plexus Block

The Evidence

The supraclavicular approach anesthetizes the brachial plexus at the level of the trunks and divisions. This block can be performed by elicitation of paresthesia, neurostimulation, or ultrasonography. The last two modalities are usually preferred. Although various surface landmarks have been described, the plumb bob technique is most commonly used [22]. For nerve stimulation, currents of 0.9 and 0.5 mA yield similar success rates, onsets, and durations of anesthesia [23]. For ultrasound guidance, the "eight ball, corner pocket" technique, whereby local anesthetic is injected at the intersection of the first rib and subclavian artery, seems to provide a reliable method to block the brachial plexus [24]. Compared to neurostimulation, ultrasonography results in a similar success rate coupled with a lower incidence of phrenic nerve blockade [25].

The Techniques

Nerve Stimulation

For the "plumb bob" technique, the patient is supine with the head turned toward the contralateral side. The head is raised to identify the insertion of the lateral border of the sternocleidomastoid on the clavicle. A 5-cm block needle is inserted at this point

Fig. 13.8 Landmarks for supraclavicular brachial plexus block (*A* subclavian artery, *SCM* sternocleidomastoid muscle)

perpendicularly to the floor (Fig. 13.8). Failure to elicit an evoked motor response should be followed by redirection of the needle in a cephalad or caudad direction (in a parasagittal plane). Care is taken not to exceed an arc of 30°. After ensuring that the evoked motor response is still present at a current of 0.9 mA or lower, 30–40 ml of local anesthetic are commonly used.

Ultrasound Guidance

The patient is supine or semisitting with the head turned toward the contralateral side. Using a high-frequency probe, the supraclavicular area is scanned to identify a short-axis view of the subclavian artery (Fig. 13.9). The first rib can be seen under the vessel. Superolateral to the artery, a collection of hypoechoic structures (trunks and divisions of the brachial plexus) can be seen. The skin and subcutaneous tissues are infiltrated with local anesthesia. Using an in-plane technique and a lateral to medial direction, a 5-cm block needle is directed toward the "corner pocket," i.e., the intersection between the subclavian artery and the first rib (Fig. 13.10). Care must be taken to visualize the entire length of the needle during the advancement process. Using a mix of lidocaine and bupivacaine, Duggan et al. [26] reported the ED50 and ED95 of ultrasound-guided supraclavicular blocks to be 23 and 42 ml, respectively.

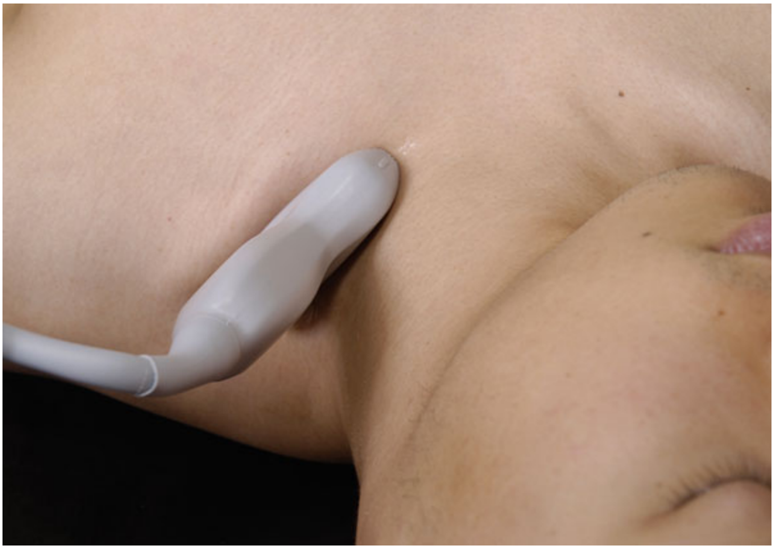

Fig. 13.9 Position of the ultrasound probe for supraclavicular brachial plexus block

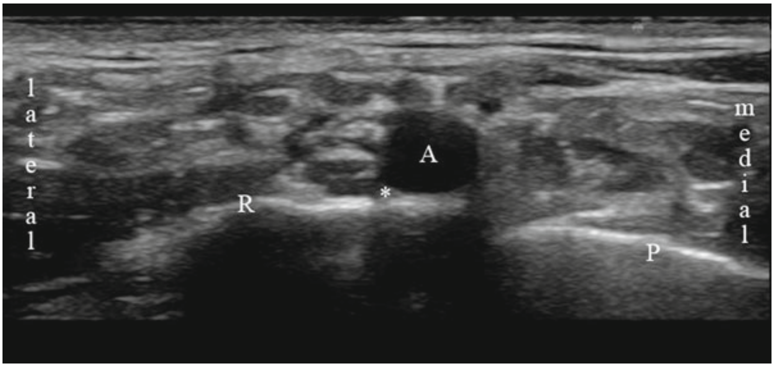

Fig. 13.10 Ultrasonographic appearance of the supraclavicular brachial plexus (*A* subclavian artery, *P* pleura, *R* first rib, *asterisk* indicates target)

Complications

Vascular puncture, recurrent laryngeal nerve paralysis, and Horner's syndrome can occur after supraclavicular blocks. The risk of pneumothorax can be as high as 6% if traditional techniques, which direct the needle in a cephalocaudal direction toward the lung, are used. Because phrenic nerve blockade can occur in 67% of cases, like its interscalene counterpart, this block is contraindicated in patients with pulmonary compromise [27].

Infraclavicular Brachial Plexus Block

The Evidence

The infraclavicular approach anesthetizes the brachial plexus at the level of its cords (lateral, posterior, and medial). This block can be performed with neurostimulation or ultrasonography. For neurostimulation-guided infraclavicular blocks, the available literature favors a double-injection technique (avoiding the musculocutaneous/median combination) or a single-injection technique aiming for radial-type stimulation [28]. The latter may be slightly superior because of a shorter performance time and better sensory blockade of the ulnar and radial nerves at 30 min [28]. For ultrasound-guided infraclavicular blocks, the optimal technique consists of a single-injection dorsal to the axillary artery [29, 30].

Comparison of nerve stimulation and ultrasonography has yielded mixed results. Two trials comparing single-stimulation infraclavicular block with single- or multiple-injection ultrasound-guided block found similar rates of surgical anesthesia and onset times [31, 32]. However, in another study, ultrasonography was associated with a higher rate of surgical anesthesia, a shorter performance time, and fewer paresthesia [33]. Although some practitioners routinely combine neurostimulation and ultrasonography, this practice seems to offer minimal benefits. Compared to ultrasound guidance alone, the combination of both modalities unnecessarily increased the performance time [34, 35] and led to a lower success rate [34].

The Techniques

Neurostimulation

Since the first description by Raj et al. [36], several sets of landmarks have been described for infraclavicular blocks. In North America, the most popular method is the pericoracoid technique [37]. With the patient supine, the arm to be blocked is adducted. A point 2 cm medial and 2 cm caudad to the tip of the coracoid process is identified [37] (Fig. 13.11). The skin and subcutaneous tissue are infiltrated with local anesthesia. A 5- to 10-cm block needle, connected to a nerve stimulator set at an initial current of 1.5 mA, a pulse width of 0.1 ms, and a frequency of 2 Hz, is inserted perpendicularly to the skin. Usually, elbow flexion (lateral cord stimulation) is encountered first. Using a parasagittal plane, the needle tip is redirected in a caudad direction in search of a radial-type response (extension of the forearm, wrist, or fingers). After ensuring that the evoked motor response is still present at a current of 0.2–0.5 mA, 30–40 ml of local anesthetic are deposited.

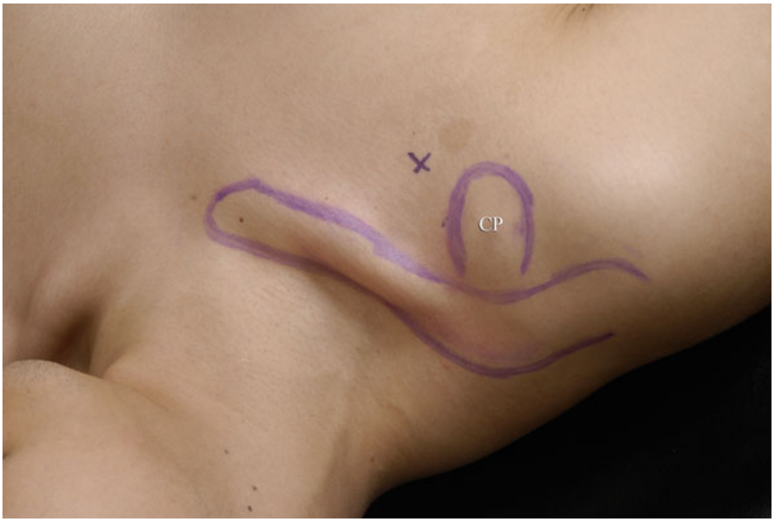

Fig. 13.11 Landmarks for infraclavicular brachial plexus block (*CP* coracoid process, *X* puncture site)

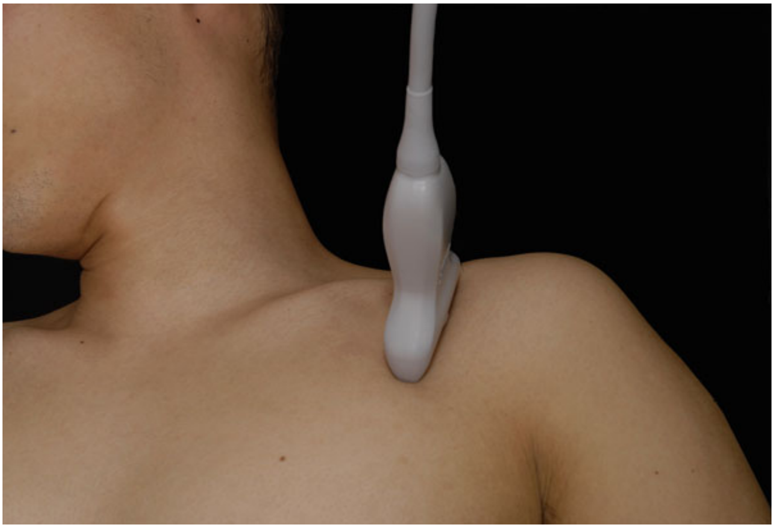

Fig. 13.12 Position of the ultrasound probe for infraclavicular brachial plexus block

Ultrasound Guidance

The patient is positioned supine. The arm is flexed so that the forearm and hand can rest comfortably on the torso. A high-frequency ultrasound probe is placed in the infraclavicular fossa, medial to the coracoid process, to obtain a short-axis view of the axillary vessels (Fig. 13.12). The axillary artery and vein can be found under

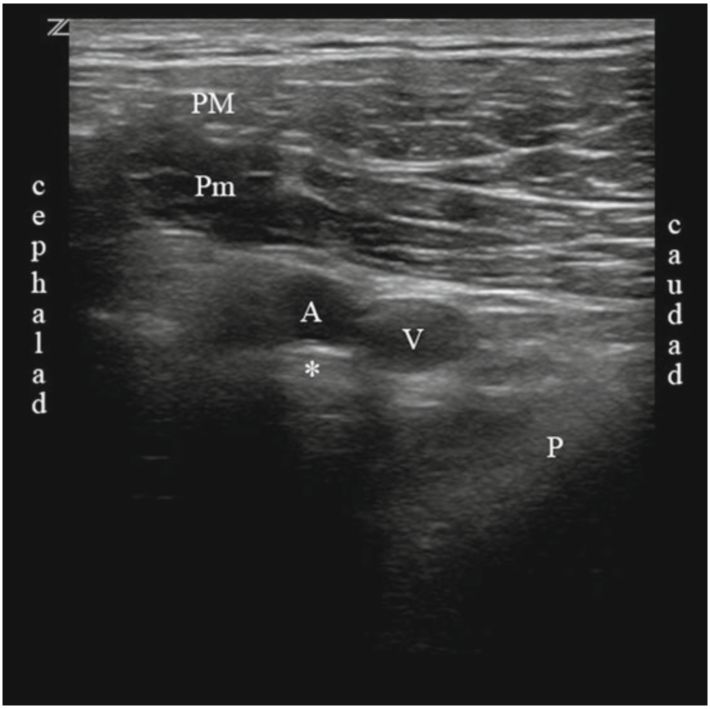

Fig. 13.13 Ultrasonographic appearance of the infraclavicular brachial plexus (*A* axillary artery, *P* pleura, *PM* pectoralis major muscle, *Pm* pectoralis minor muscle, *V* axillary vein, *asterisk* indicates target)

the pectoralis major and minor muscles. The pleura can sometimes be seen under the vessels (Fig. 13.13). Local anesthetic is used to infiltrate the skin, subcutaneous tissues, and pectoralis muscles. Using an in-plane technique and a cephalad to caudad direction, a 10-cm block needle is advanced until the tip lies just dorsal to the artery. Care must be taken to visualize the needle during the advancement process. Usually, a pop can be felt just before the needle assumes the correct position. Thirty to forty milliliters of local anesthetic agent are injected.

Complications

Vascular puncture can occur. Because of the depth of the vessels, external compression can be difficult to achieve. Thus, caution should be exercised in coagulopathic patients, and perhaps, a different approach should be considered. There have also been anecdotal reports of Horner's syndrome, phrenic paralysis [38], and pneumothorax [39] associated with infraclavicular blocks.

Axillary Brachial Plexus Block

The Evidence

The axillary approach anesthetizes the brachial plexus at the level of its four main terminal branches (musculocutaneous, median, radial, and ulnar nerves). Performing this block by fascial clicks, elicitation of paresthesia, transarterial injection, and single-nerve stimulation yields a similar success rate between 70 and 80% [40]. Thus, most practitioners prefer multiple-nerve stimulation and ultrasound guidance.

With neurostimulation, evidence suggests that a three-injection technique (in which the ulnar nerve is not located) provides a similar efficacy to the four-injection technique [41]. A triple-stimulation technique seeking the median, musculocutaneous, and radial nerves, as opposed to the median, musculocutaneous, and ulnar nerves, also seems to provide a higher success rate [42]. Furthermore, for the radial nerve, a distal motor response (wrist or finger extension) should be preferred to a proximal response (forearm extension) [43].

Compared to a multiple-stimulation technique, a higher success rate and shorter onset time have been reported with ultrasonography [44]. However, another trial found similar success rates [45].

The Techniques

Nerve Stimulation

The patient is positioned with the shoulder abducted and the elbow flexed. The axillary area is palpated to identify the axillary artery. In the axilla, the musculocutaneous and median nerves are most often situated above the artery, whereas the radial and ulnar nerves can be found below the latter. However, a great deal of anatomical variability can occur. For this block, two distinct puncture sites (above and below the artery) are required (Fig. 13.14). The skin is infiltrated with local anesthesia. Because the median nerve is very superficial, a small volume (<0.3 ml) should be used above the artery; otherwise, the evoked motor response may be abolished for the median nerve. A 5-CM block needle, connected to a nerve stimulator set at an initial current of 1.5 mA, a pulse width of 0.1 ms, and a frequency of 2 Hz, is commonly used. The block needle is first inserted above the artery to locate the musculocutaneous nerve (elbow flexion). After ensuring that the evoked motor response is still present at a current of 0.2–0.5 mA, 5–7 ml of local anesthetic are deposited. Subsequently, the needle is repositioned to locate the median nerve (above the artery) and radial nerve (below the artery). Wrist/finger flexion is sought for the former, whereas wrist/finger extension is sought for the latter. For each of these two nerves, a local anesthetic volume of 10–14 ml can be used.

Fig. 13.14 Landmarks for axillary brachial plexus block (*X* puncture sites)

Fig. 13.15 Position of the ultrasound probe for axillary brachial plexus block

Ultrasound Guidance

The patient is positioned with the shoulder abducted and the elbow flexed. The axilla is scanned with a high-frequency linear ultrasound probe to identify a short-axis view of the axillary artery (Fig. 13.15). The musculocutaneous nerve, a hyperechoic structure,

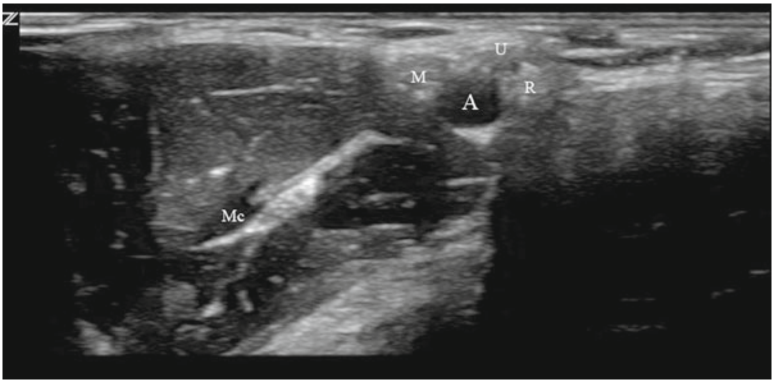

Fig. 13.16 Ultrasonographic appearance of the axillary brachial plexus (*A* axillary artery, *M* median nerve, *Mc* musculocutaneous nerve, *R* radial nerve, *U* ulnar nerve)

can be found anterior and lateral to the artery, in the belly of the coracobrachialis muscles, or in a plane between the coracobrachialis and biceps muscles (Fig. 13.16).

Using an in-plane technique, the skin and subcutaneous tissues are infiltrated with local anesthesia. A 5-cm block needle is then inserted. Care must be taken to visualize the entire length of the needle during the advancement process. The needle is first directed toward the musculocutaneous nerve. Five to seven milliliters of local anesthetic are injected. Subsequently, the needle is redirected toward each of the three remaining nerves: local anesthetic is injected until circumferential spread is achieved for each of them. Although a recent report has advocated a volume as low as 1 ml per nerve [46], in practice, volumes of 5–10 ml can be used. Alternatively, if all three nerves cannot be identified, a perivascular technique can be performed whereby multiple injections are carried out until the axillary artery is surrounded by local anesthetic (donut sign).

Complications

Transient numbness, vascular puncture, intravascular injection, bruising, and soreness at the injection site have been reported, but the overall safety margin for the block is very high.

Humeral Canal Block

The Evidence

Similar to the axillary approach, the humeral canal block anesthetizes the brachial plexus at the level of the terminal branches.

The Techniques

Nerve Stimulation

The patient is positioned with the shoulder abducted and the elbow flexed. Midway between the shoulder and elbow, the arm is palpated to identify the axillary artery. The musculocutaneous and median nerves are most often situated above the artery, whereas the radial and ulnar nerves can be found below the latter. However, the radial nerve can be difficult to find because it courses posterior to the humerus. For this block, two distinct puncture sites (above and below the artery) are required (Fig. 13.17). Because the median and ulnar nerves are very superficial, a small volume (<0.3 ml) is used; otherwise, the evoked motor responses could be abolished. A 5-cm block needle, connected to a nerve stimulator set at an initial current of 1.5 mA, a pulse width of 0.1 ms, and a frequency of 2 Hz, is commonly used. The needle is first inserted above the artery to locate the musculocutaneous (elbow flexion) and median (wrist/finger flexion) nerves. Subsequently, the needle is repositioned under the artery to locate the radial (wrist/finger extension) and ulnar (extension of the fourth/fifth fingers and ulnar deviation of the wrist) nerves. For the median and radial nerve, currents of 0.8 mA or lower and 0.6 mA or lower should be used, respectively. For the ulnar and musculocutaneous, a threshold of 0.7 mA or lower is recommended [47]. A volume of 5–7 ml of local anesthetic is deposited for each nerve.

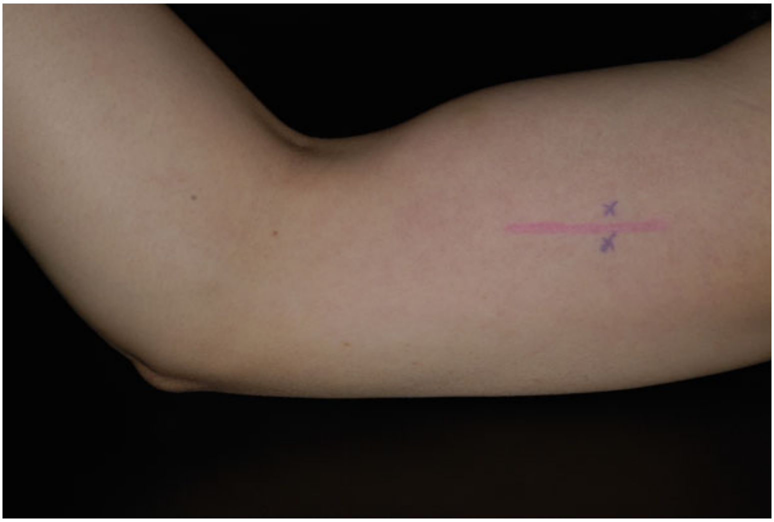

Fig. 13.17 Landmarks for humeral canal block (*X* puncture sites)

Fig. 13.18 Position of the ultrasound probe for humeral canal block

Ultrasound Guidance

The patient is positioned with the shoulder abducted and the elbow flexed. The arm is scanned with a high-frequency, linear ultrasound probe to identify a short-axis view of the axillary artery (Fig. 13.18). The musculocutaneous and median nerves are situated above the artery, whereas the radial and ulnar nerves can be located below the latter (Fig. 13.19). Using an in-plane technique and puncture sites above or below the artery, a 5-cm block needle is directed toward each of the four neural structures. Care must be taken to visualize the entire length of the needle during the advancement process. Local anesthetic is injected until circumferential spread is achieved for each nerve. Five to seven milliliters are commonly used per nerve.

Complications

Although vascular puncture, bruising, and soreness at the injection site can occur, the overall safety margin for the block is very high.

Supplemental Blocks

In the event of an incomplete brachial plexus block, missing nerves can be anesthetized in a more distal location.

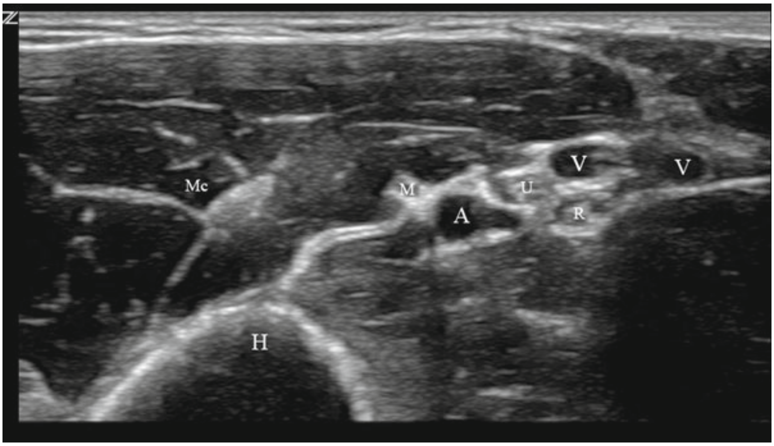

Fig. 13.19 Ultrasonographic appearance of nerves in the humeral canal (*A* brachial artery, *H* humerus, *M* median nerve, *Mc* musculocutaneous nerve, *R* radial nerve, *U* ulnar nerve, *V* brachial vein)

Suprascapular Nerve Block

The Evidence

The suprascapular nerve can be blocked with neurostimulation or ultrasonography. No randomized control trial has compared these two modalities. Cadaveric dissection suggests that ultrasonography targets the suprascapular nerve in the suprascapular fossa, whereas nerve stimulation contacts the nerve in the notch [48].

The Techniques

Neurostimulation

The patient is positioned sitting and leaning forward slightly. The spine of the scapula is identified and is traced. A vertical line passing through the tip of the scapula is also drawn. These two lines divide the scapula into four quadrants. A bisector is drawn for the superolateral quadrant. The puncture site is located 2–3 cm along this bisector (Fig. 13.20). A 5-cm block needle, connected to a nerve stimulator set at an initial current of 1.5 mA, a pulse width of 0.1 ms, and a frequency of 2 Hz, is commonly used. The needle is introduced at this point perpendicular to the skin. If the scapula is contacted, the needle is redirected superior and medially to enter the suprascapular notch. Abduction or external rotation of the arm is sought. After ensuring that the evoked motor response is still present at a current of 0.2–0.5 mA, 10 ml of local anesthetic are deposited.

Fig. 13.20 Landmarks for suprascapular nerve block (*X* puncture site)

Fig. 13.21 Position of the ultrasound probe for suprascapular nerve block

Ultrasound Guidance

The patient is positioned in the lateral decubitus position so that the side to be blocked is nondependant (Fig. 13.21). Using a high-frequency, linear ultrasound probe, the area cephalad to the scapular spine is scanned to identify the suprascapular

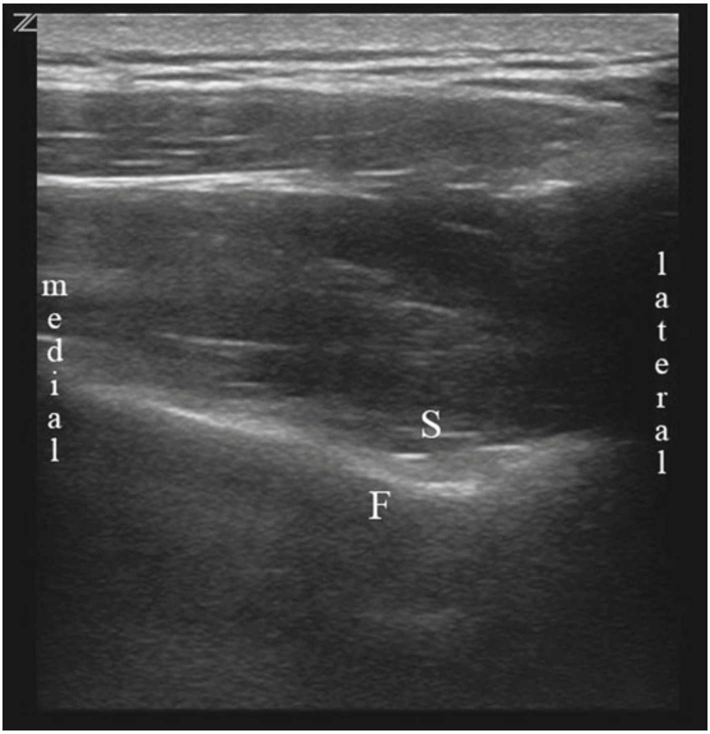

Fig. 13.22 Ultrasonographic appearance of the suprascapular fossa (*F* fossa, *S* supraspinatus muscular fascia)

fossa (Fig. 13.22). The skin and subcutaneous tissues are infiltrated with local anesthesia. Using an in-plane technique, a 10-cm block needle is advanced toward the suprascapular fossa. Care must be taken to visualize the needle during the advancement process. The entire length of the needle may not be visible due to the steep angle of advancement. However, its tip can be followed through tissue distortion. A volume of 10 ml of local anesthetics is deposited in the fossa.

Upper Extremity Distal Nerve Blocks (Radial, Median, and Ulnar Nerves)

The Evidence

The radial, median, and ulnar nerves can be blocked at the elbow or wrist. Blocks performed at the elbow offer more versatility because they can be used for forearm, wrist, and hand surgery. In contrast, blocks performed at the wrist can only be used for procedures involving the hand. To date, no study has compared elicitation of paresthesia, neurostimulation, and ultrasonography for elbow blocks.

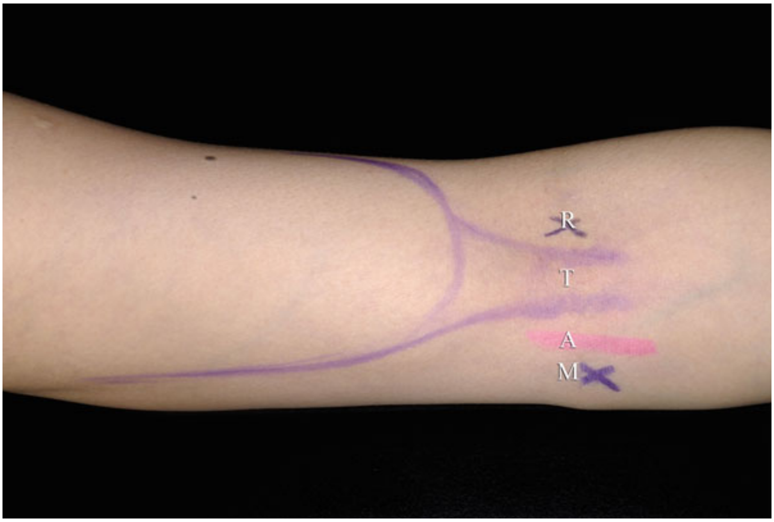

Fig. 13.23 Landmarks for supplemental median and radial nerve blocks at the elbow (*A* brachial artery, *M* median nerve, *R* radial nerve, *T* bicipital tendon)

The Techniques

At the Elbow

Neurostimulation

(a) Radial Nerve
The patient is supine with the upper extremity supinated and abducted. The radial nerve is located lateral to the bicipital tendon between the brachialis and brachioradialis muscles (Fig. 13.23). A 2.5-cm block needle, connected to a nerve stimulator set at an initial current of 1.5 mA, a pulse width of 0.1 ms, and a frequency of 2 Hz, is commonly used. The needle is inserted to a depth of 1–2 cm. Wrist or finger extension is sought. After ensuring that the evoked motor response is still present at a current of 0.2–0.5 mA, 5–7 ml of local anesthetic are deposited.

(b) Median Nerve
The patient is supine with the upper extremity supinated and abducted. The median nerve is located just medial to the brachial artery (Fig. 13.23). A 2.5-cm block needle, connected to a nerve stimulator set at an initial current of 1.5 mA, a pulse width of 0.1 ms, and a frequency of 2 Hz, is commonly used. The needle is inserted medial to the brachial artery at a depth of 1–2 cm. Wrist or finger flexion is sought. After ensuring that the evoked motor response is still present at a current of 0.2–0.5 mA, 5–7 ml of local anesthetic are deposited.

Fig. 13.24 Landmarks for supplemental ulnar nerve block at the elbow (*E* medial epicondyle, *O* olecranon, *X* puncture site)

(c) Ulnar Nerve
The patient is supine with the forearm flexed on the arm to locate the ulnar groove. The nerve is located in the groove between the medial epicondyle and the olecranon process (Fig. 13.24). A 2.5-cm block needle, connected to a nerve stimulator set at an initial current of 1.5 mA, a pulse width of 0.1 ms, and a frequency of 2 Hz, is commonly used. The block needle is inserted 1–3 cm proximal to a line joining the bony landmarks and directed along the longitudinal axis of the humerus. Ulnar deviation of the wrist and flexion of the little finger are sought. After ensuring that the evoked motor response is still present at a current of 0.2–0.5 mA, 5–7 ml of the local anesthetic agent are deposited.

Ultrasound Guidance

(a) Radial Nerve
The patient is positioned supine with the upper extremity abducted. At the level of the elbow crease, a high-frequency, linear ultrasound probe is used (Fig. 13.25). The radial nerve appears as a hyperechoic crescent (Fig. 13.26). Using an in-plane technique, a 5-cm block needle is advanced toward the nerve. A volume of 5–7 ml of local anesthetic is deposited.

(b) Median Nerve
The patient is supine with the upper extremity abducted. At the level of the elbow crease, a high-frequency, linear ultrasound probe is used (Fig. 13.25). The median nerve is located medial to the brachial artery (Fig. 13.27). Using an in-plane technique, a 5-cm block needle is advanced toward the nerve. A volume of 5–7 ml of local anesthetic is deposited.

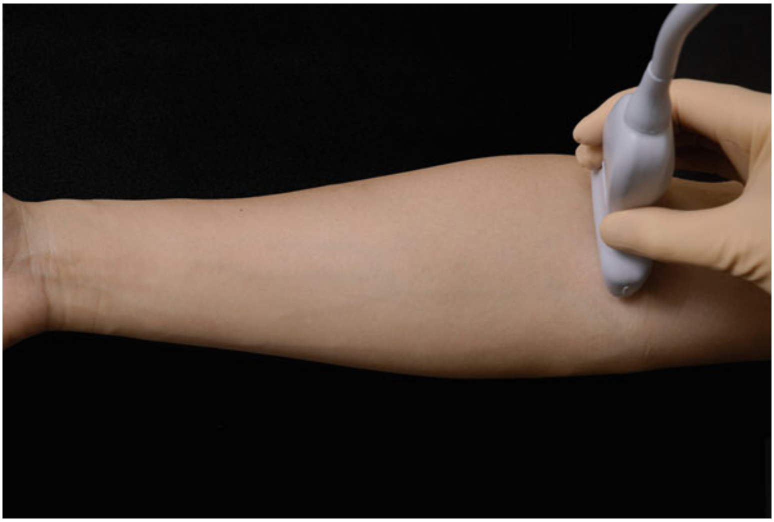

Fig. 13.25 Position of the ultrasound probe for supplemental median and radial nerve blocks at the elbow

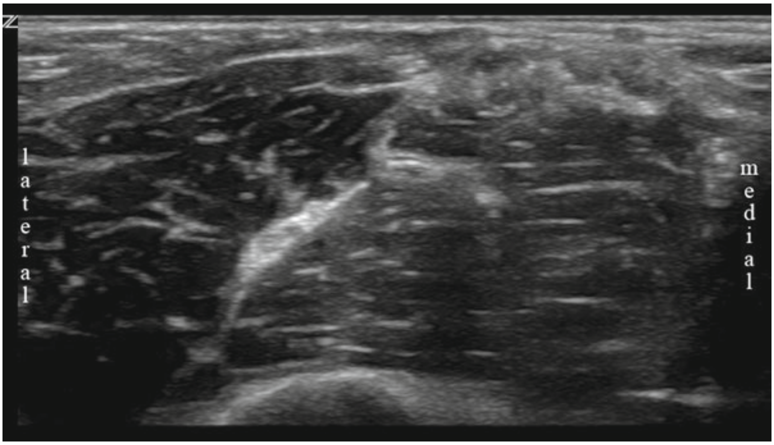

Fig. 13.26 Ultrasonographic appearance of the radial nerve at the elbow

(c) Ulnar Nerve
The patient is positioned supine. The elbow is flexed and the forearm internally rotated so that its radial aspect rests comfortably on the torso. A high-frequency, linear ultrasound probe is used to scan the proximal forearm (Fig. 13.28). The ulnar nerve appears as a hyperechoic structure (Fig. 13.29). Using an in-plane technique, a 5-cm block needle is advanced toward the nerve. A volume of 5–7 ml of local anesthetic is deposited.

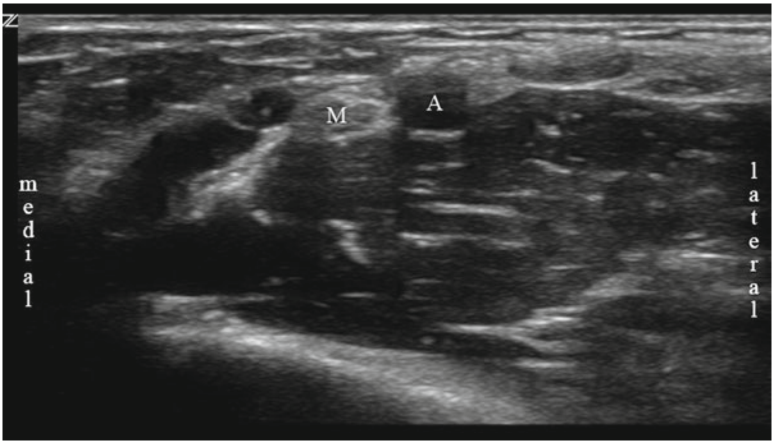

Fig. 13.27 Ultrasonographic appearance of the median nerve at the elbow (*A* brachial artery, *M* median nerve)

Fig. 13.28 Position of the ultrasound probe for supplemental ulnar nerve block at the elbow

At the Wrist

(a) Radial Nerve
The radial nerve can be blocked at the wrist without the use of neurostimulation or ultrasonography. A field block is performed by injecting 5–7 ml of local anesthetic subcutaneously in and around the anatomical "snuff box" (Fig. 13.30).

(b) Median and Ulnar Nerves

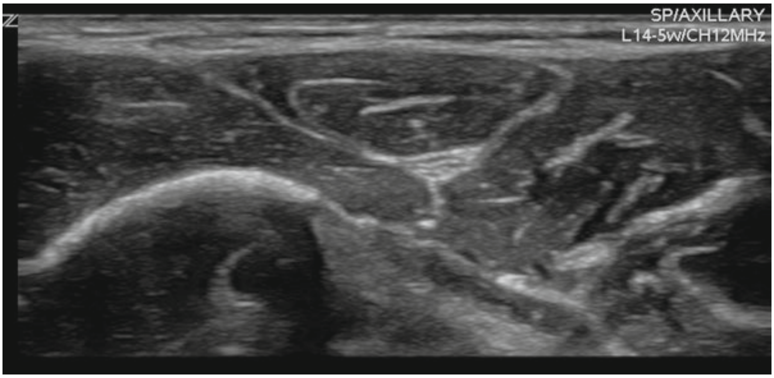

Fig. 13.29 Ultrasonographic appearance of the ulnar nerve at the elbow

Fig. 13.30 Landmarks for supplemental radial nerve block at the wrist (*X* site of infiltration)

Neurostimulation

(a) Median
The median nerve is located between the tendons of the flexor palmaris longus and the flexor carpi radialis (Fig. 13.31). A 2.5-cm block needle, connected to a nerve stimulator set at an initial current of 1.5 mA, a pulse width of 0.1 ms, and a frequency of 2 Hz, is commonly used. The block needle is introduced approximately 3 cm above the wrist crease. Thumb flexion is sought. After ensuring that the evoked motor response is still present at a current of 0.2–0.5 mA, 3–5 ml of local anesthetic are deposited.

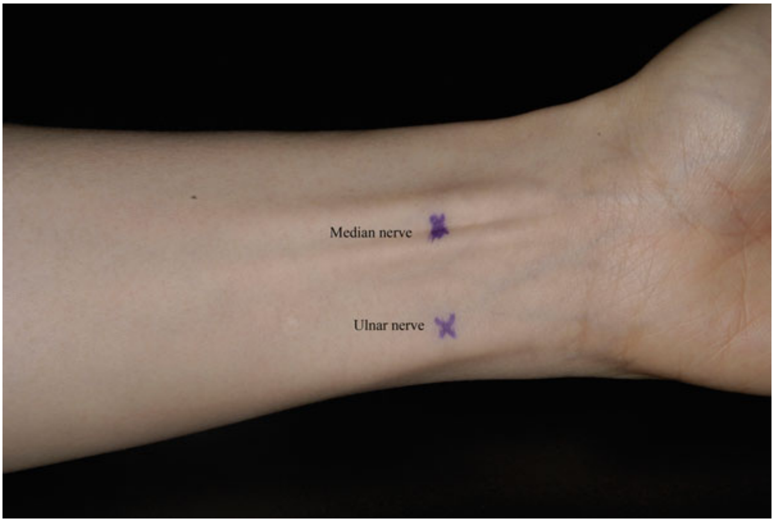

Fig. 13.31 Landmarks for supplemental median and ulnar nerve block at the wrist

(b) Ulnar
The ulnar nerve is located medial to the ulnar artery, below the tendon of the flexor carpi ulnaris muscle. A 2.5-cm block needle, connected to a nerve stimulator set at an initial current of 1.5 mA, a pulse width of 0.1 ms, and a frequency of 2 Hz, is commonly used. The block needle is introduced medial to the artery, 3 cm proximal to the wrist crease (Fig. 13.31). Flexion of the fifth finger is sought. After ensuring that the evoked motor response is still present at a current of 0.2–0.5 mA, 3–5 ml of local anesthetic are deposited.

Ultrasound Guidance

The patient is positioned supine with the upper extremity abducted. The distal forearm is scanned with a high-frequency, linear ultrasound probe (Fig. 13.32). The median nerve appears in the middle of the screen (Fig. 13.33). The ulnar nerve is medial to the ulnar artery (Fig. 13.34). Using an in-plane technique, a 2.5–5-cm block needle is advanced toward each nerve. A volume of 5–7 ml of local anesthetic is deposited for each nerve.

Digital Nerve Block

This block is performed with the hand in the prone position. A 2.5-cm block needle is introduced into the web space of the finger to be anesthetized: this corresponds to the proximal phalanx. A volume of 1–2 ml of local anesthetic is deposited on either side of the finger.

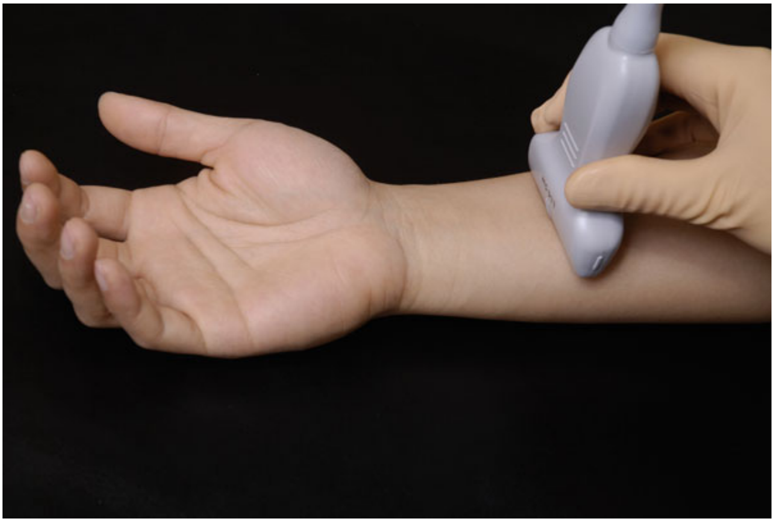

Fig. 13.32 Position of the ultrasound probe for supplemental median and ulnar nerve block at the elbow

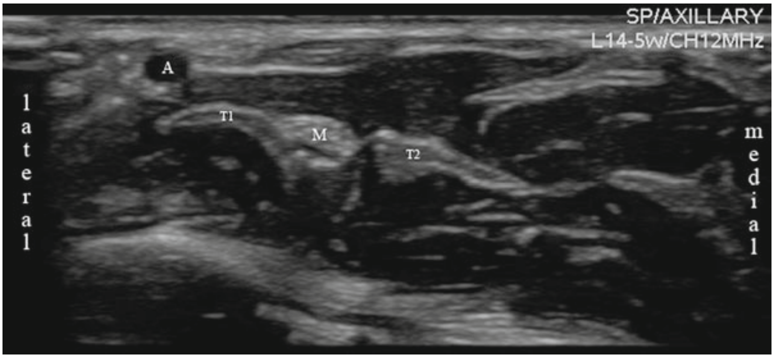

Fig. 13.33 Ultrasonographic appearance of the median nerve at the wrist (*A* radial artery, *M* median nerve, *T1* tendon of the flexor carpi radialis muscle, *T2* tendon of the palmaris longus muscle)

Complications

Most supplemental blocks possess a high safety profile. Vascular puncture (brachial, ulnar, or suprascapular arteries) can occur. For suprascapular nerve blockade, care must be taken not to advance the needle too far past the suprascapular notch: this can lead to a pneumothorax.

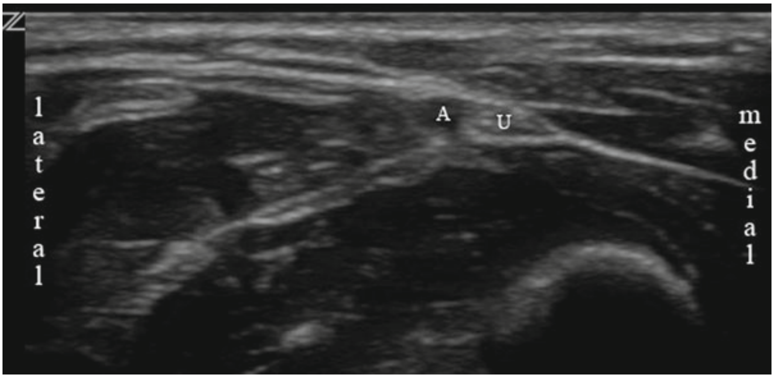

Fig. 13.34 Ultrasonographic appearance of the ulnar nerve at the wrist (*A* ulnar artery, *U* ulnar nerve)

Continuous Brachial Plexus Block

The Evidence

Continuous brachial plexus blockade can be achieved using a blind catheter, a technique whereby the block needle locates the plexus with neurostimulation, and the catheter is simply advanced 1–5 cm past the needle tip. Alternatively, a stimulating catheter can be used: after the obtention of a satisfactorily evoked motor response with the needle, the nerve stimulator is connected to the catheter to ensure that, during the latter's advancement, muscular contractions are preserved. Lastly, ultrasound guidance can also be used to confirm the proximity of needle and catheter to the brachial plexus.

To date, two trials have compared these different techniques. In the setting of shoulder surgery, blind and ultrasound-guided interscalene catheters resulted in similar pain scores and local anesthetic/opioid consumption postoperatively. However, ultrasonography yielded a slightly quicker performance time and lower block-related pain score [49]. The second study compared blind, stimulating, and ultrasound-guided infraclavicular catheters. Unfortunately, the results are difficult to interpret because of the differences in evoked motor responses between groups [50]. Although two trials have demonstrated that, compared to neurostimulation, ultrasound guidance resulted in a quicker performance time for interscalene and infraclavicular catheters, these studies did not rigorously assess pain control during the postoperative infusion of local anesthetic [51, 52].

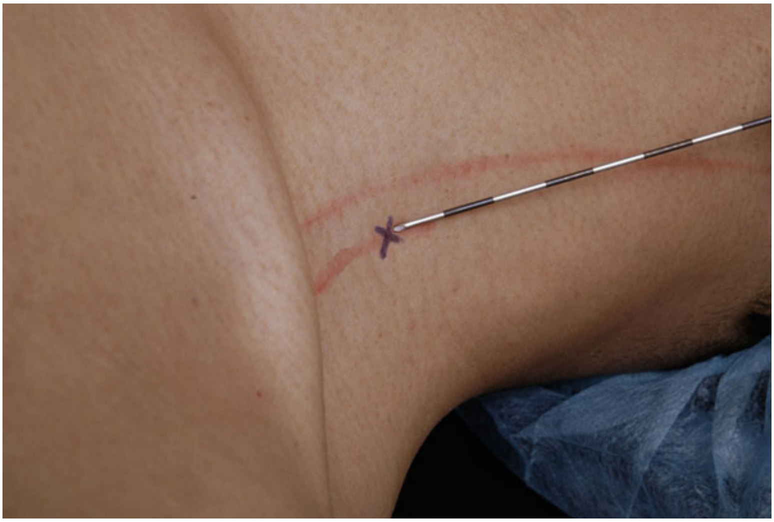

Fig. 13.35 Needle angulation for continuous neurostimulation-guided interscalene brachial plexus block

The Techniques

Blind and Stimulating Catheters

With landmarks similar to single-shot blocks, the block needle is used to locate the brachial plexus. Because neural structures are very superficial in the interscalene and axillary areas, the needle should be inserted with a flat angle to the skin to facilitate subsequent catheter advancement (Figs. 13.35 and 13.36). Although some authors dilate the perineural sheath with a small bolus (5–10 ml) of D5W prior to threading the catheter, this seems to provide minimal benefits [53]. For blind catheters, normal saline or local anesthetic can be used; for stimulating catheters, D5W will preserve the evoked motor response for catheter advancement. After a satisfactorily evoked motor response is obtained with the needle at 0.5 mA, the blind catheter is simply advanced 3–4 cm past the needle tip. A distance greater than 4 cm should be avoided to prevent catheter coiling [54]. If a stimulating catheter is used, the nerve stimulator is disconnected from the needle and connected to the catheter. During the advancement process (3–4 cm), care must be taken to ensure that the evoked motor response and stimulatory threshold do not change. The operator may need to withdraw the catheter into the needle and change the latter's bevel orientation or angulation to accomplish this. After the blind or stimulating catheter has been successfully inserted, the needle is carefully withdrawn over the catheter and the latter secured with adhesive dressings.

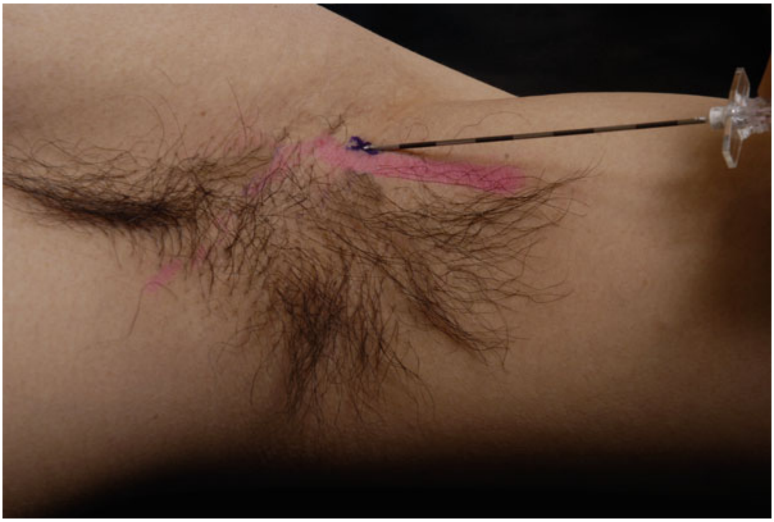

Fig. 13.36 Needle angulation for continuous neurostimulation-guided axillary brachial plexus block

Ultrasound Guidance

After the bolus of local anesthetic has been injected through the needle, the catheter is advanced 3–4 cm past the needle tip. Care must be taken to visualize in real time its passage into the perineural space (Fig. 13.37). This may require the help of an assistant, as a third hand is needed to hold the probe while the operator inserts the catheter through the needle. If the catheter cannot be seen with certainty, its tip can be identified with the injection of a few milliliters of local anesthetics or saline. Alternately, 1 ml of air can be used. This will produce an unmistakable hyperechoic shadow. Air should be used sparingly in order to preserve the quality of the image. After successful placement of the ultrasound-guided catheter, the needle is carefully withdrawn over the catheter and the latter secured with adhesive dressings.

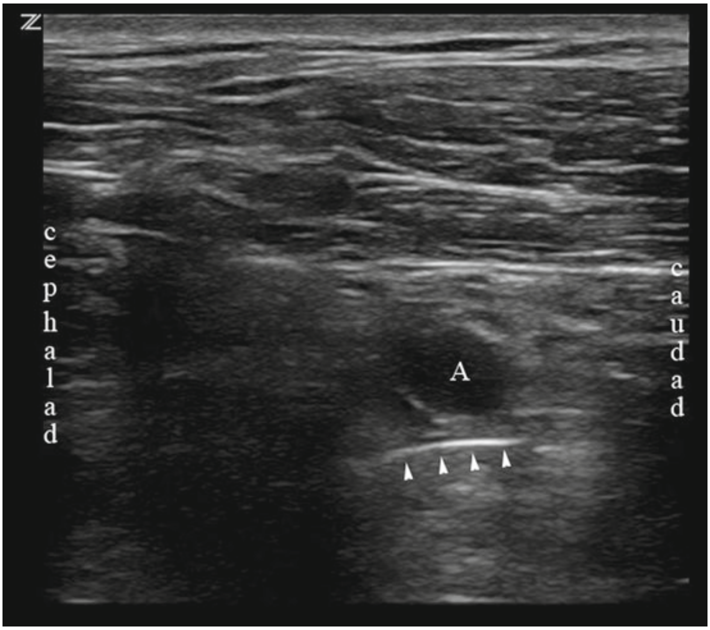

Fig. 13.37 Ultrasonographic appearance of a continuous infraclavicular catheter inserted with ultrasonography (*A* axillary artery, *arrows* indicate catheter)

Clinical Pearls

Clinical Anatomy of the Brachial Plexus

- Although most textbooks recommend selecting nerve blocks based on the cutaneous innervation of the surgical site (Fig. 13.38), knowledge of the osseous innervation (Fig. 13.2) is far more important as postoperative pain rarely stems from trauma to skin.
- The medial and lateral pectoral nerves (which innervate the pectoral muscles) arise from the medial and lateral cords, respectively. Thus, pectoral contraction is an acceptable evoked motor response when performing neurostimulation-guided interscalene or cervical paravertebral brachial plexus block.
- Pectoral contraction should not be accepted for neurostimulation-guided infraclavicular brachial plexus block since it is difficult to differentiate between electrolocation of the nerves and direct stimulation of the pectoral muscles.
- The suprascapular nerve originates from the superior trunk and supplies the posterior aspect of the shoulder. For surgical procedures involving the shoulder joint, it is important to block this nerve before its take-off from the superior trunk. This is best achieved with an interscalene, cervical paravertebral, or supraclavicular approach.

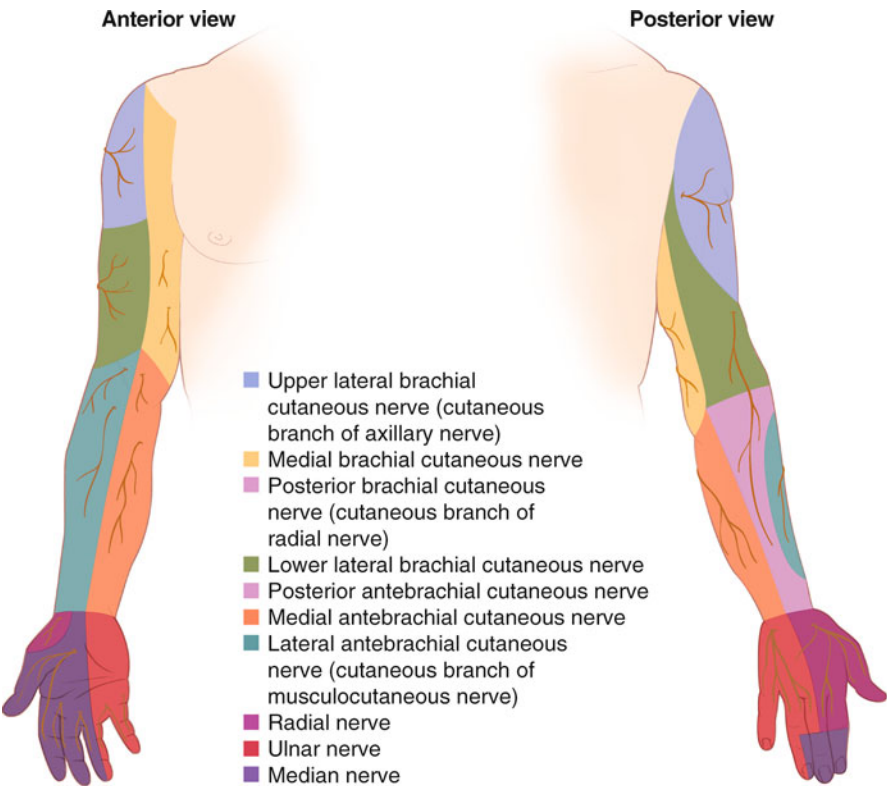

Fig. 13.38 Cutaneous innervation of the upper extremity

- The nerve to the subclavius muscle originates from the superior trunk and is responsible for the bony innervation of the clavicle. For procedures involving the clavicle, an interscalene, cervical paravertebral, or supraclavicular brachial plexus block will enable this nerve to be blocked proximal to its bifurcation.

Choosing the Right Approach

- For single-shot blocks, the cervical paravertebral, interscalene, and supraclavicular approaches can be used to anesthetize the brachial plexus. For continuous perineural catheters, interscalene and cervical paravertebral blocks offer an advantage over supraclavicular blocks because of the latter's proximity to the surgical site. Cervical paravertebral catheters provide an elegant option because they can be tunneled around the hairline and secured on the nonoperative shoulder.
- In light of the comparable efficacy, the selection between supraclavicular, infraclavicular, axillary, and humeral canal approaches should be dictated by potential

adverse events and patient characteristics. For instance, supraclavicular blocks, and their inherent risk of phrenic paralysis, should be avoided in patients with pulmonary compromise. Infraclavicular blocks may be technically difficult in subjects with ample pectoral muscles or breast tissue. Axillary and humeral canal blocks should be avoided in patients (with fractures) who cannot comfortably abduct the upper limb.

Interscalene Brachial Plexus Block

- To ensure that the interscalene groove has been properly identified, palpation of the latter above the clavicle should reveal the presence of an arterial pulsation (subclavian artery).
- If interscalene blocks are performed postoperatively with nerve stimulation, shoulder elevation (dorsal scapular nerve stimulation) can be mistaken for abduction (brachial plexus stimulation) because of the presence of slings and surgical dressings. Before injecting the local anesthetic, the operator should palpate the deltoid muscle and confirm the presence of abduction.
- If the brachial plexus cannot be identified with ultrasonography at the interscalene level, the supraclavicular area can be scanned to locate the subclavian artery. Typically, the brachial plexus (cluster of trunks and divisions) is situated superolateral to the latter. Next, the plexus is slowly traced back toward the cricoid cartilage until it becomes a column of hypoechoic nodules (roots or trunks).

Supraclavicular Brachial Plexus Block

- For neurostimulation, a distal evoked motor response (wrist or hand) seems to provide a better block.
- The risk of pneumothorax is decreased when this block is performed with ultrasound guidance because the entire length of the needle can be visualized.
- Ultrasound-guided injection into the hypoechoic cluster of trunks and divisions reliably anesthetizes the arm and forearm but may spare the hand.

Infraclavicular Brachial Plexus Block

- Magnetic resonance imaging reveals a great deal of anatomic variability in the location of the three cords around the axillary artery. For instance, despite its name, the medial cord is usually posterior (dorsal) to the artery [55].
- With the pericoracoid technique, in order to minimize the risk of pneumothorax, the needle should never be directed medially when searching for the appropriate evoked motor response.

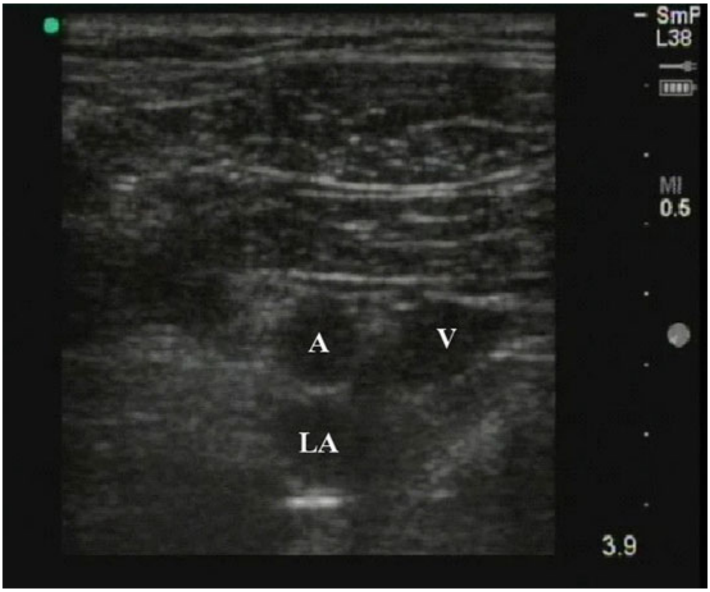

Fig. 13.39 The "Double Bubble" sign (A axillary artery, LA local anesthetic agent, V axillary vein)

- If the needle tip is correctly located with ultrasonography, injection of the first few milliliters of local anesthetic will give a picture resembling a "double bubble" [56]. The "superior bubble" represents the axillary artery in a short axis, and the "inferior bubble," the pool of local anesthetic (Fig. 13.39). As more local anesthetic is deposited, the inferior bubble will turn into a U shape, wrapping itself around the artery, and the latter will be gently pushed ventrally. If a "double bubble" fails to form, the needle tip may be too dorsal in relation to artery; thus, it should be repositioned to lie immediately adjacent to the vessel.
- Occasionally, two axillary veins (cephalad and caudad to the artery) can be present. In this situation, another approach should be considered to avoid vascular puncture.

Axillary Brachial Plexus Block

- If an evoked motor response cannot be obtained, the musculocutaneous nerve can be blocked by contacting the humerus and injecting local anesthetic as the needle is pulled back into the belly of the coracobrachialis muscle. Two or three passes (with different angulations) are needed.
- Care must be taken not to apply too much pressure with the ultrasound probe. This may lead to compression of superficial veins and unrecognized intravascular injection [57].

Humeral Canal Block

- For ultrasound-guided humeral canal blocks, if the radial nerve cannot be identified dorsal to the humerus, the probe can be moved proximally toward the axilla: the nerve will be located more superficially around the brachial artery.
- If the musculocutaneous, median, and ulnar nerves cannot be identified, they can be traced from the axilla downward. Alternatively, the median and ulnar nerves can be traced back from the elbow.

Supplemental Blocks

- At the elbow, for ulnar nerve block, local anesthetic should not be injected directly into the groove: high pressure in this tight fascial compartment can damage the nerve.
- Although many textbooks recommend supplementing brachial plexus blocks with an intercostobrachial nerve block (subcutaneous infiltration of the medial arm with 5–7 ml of local anesthetic) for tourniquet tolerance, this step is seldom necessary. Tourniquet-related pain stems from muscular compression and should be covered by the brachial plexus block. In contrast, the intercostobrachial nerve only provides sensory innervation to the skin.
- For digital nerve block, epinephrine must be avoided in the local anesthetic solution as this may produce ischemia of the fingertips.

Continuous Brachial Plexus Block

- The insertion of stimulating perineural catheters may require multiple attempts. A systematic approach is required to find the optimal combination of needle angulation and bevel orientation. The needle is first rotated 90° at a time to attempt catheter advancement. After the four quadrants have been unsuccessfully explored, the needle angulation is changed and the four quadrants tried again. These two steps (change of angulation and exploration of four quadrants) are repeated until the catheter can be inserted 3–4 cm past the needle tip with preservation of the evoked motor response.
- The optimal stimulatory threshold for perineural catheter placement has not been established. In their practice, the authors tolerate a threshold as high as 0.8 mA (pulse width = 0.1 ms).

Multiple-Choice Questions

1. All the following nerves originate from the brachial plexus EXCEPT:
   (a) Thoracodorsal nerve
   (b) Intercostobrachial nerve
   (c) Lateral pectoral nerve
   (d) Long thoracic nerve

2. All the following nerves originate from the C5 nerve root EXCEPT:
   (a) Suprascapular nerve
   (b) Dorsal scapular nerve
   (c) Phrenic nerve
   (d) Ulnar nerve

3. An injury to the posterior cord will lead to all the following deficits EXCEPT:
   (a) Decreased shoulder abduction
   (b) Decreased elbow extension
   (c) Decreased sensation of the lateral aspect of the shoulder
   (d) Decreased sensation over the medial aspect of the forearm

4. For clavicular surgery, all the following blocks provide adequate postoperative analgesia EXCEPT:
   (a) Cervical paravertebral block
   (b) Supraclavicular block
   (c) Superficial cervical plexus block
   (d) None of the above

5. For shoulder surgery, all the following blocks provide adequate postoperative analgesia EXCEPT:
   (a) Infraclavicular combined with suprascapular nerve blocks
   (b) Infraclavicular combined with superficial cervical plexus blocks
   (c) Cervical paravertebral block
   (d) None of the above

6. For elbow surgery, all the following blocks provide adequate postoperative analgesia EXCEPT:
   (a) Infraclavicular block
   (b) Axillary block
   (c) Supraclavicular block
   (d) None of the above

7. For hand surgery, all the following blocks provide adequate postoperative analgesia EXCEPT:
   (a) Interscalene block
   (b) Humeral canal block
   (c) Supraclavicular block
   (d) None of the above

8. All the following are potential side effects of interscalene blocks EXCEPT:
   (a) Hoarseness
   (b) Exophthalmos
   (c) Myosis
   (d) Dyspnea

9. All the following are potential side effect of infraclavicular blocks EXCEPT:
   (a) Horner's syndrome
   (b) Dyspnea
   (c) Winged scapula
   (d) Perioral numbness

10. All the following evoked motor responses are acceptable for neurostimulation-guided interscalene blocks EXCEPT:
    (a) Shoulder elevation
    (b) Pectoral contraction
    (c) Finger flexion
    (d) Wrist extension

11. All the following evoked motor responses are acceptable for neurostimulation-guided infraclavicular blocks EXCEPT:
    (a) Pectoral contraction
    (b) Elbow extension
    (c) Wrist extension
    (d) Finger flexion

12. Which of the following evoked motor responses is considered suboptimal in the performance of neurostimulation-guided axillary blocks?
    (a) Elbow flexion
    (b) Elbow extension
    (c) Thumb opposition
    (d) Wrist extension

13. With ultrasonography, all the following structures are hyperechoic EXCEPT:
    (a) Musculocutaneous nerve
    (b) Lateral cord
    (c) Superior trunk
    (d) Median nerve in the forearm

14. With ultrasonography, all the following structures are hypoechoic EXCEPT:
    (a) Inferior trunk
    (b) Phrenic nerve
    (c) C7 root
    (d) Medial cord

15. With ultrasonography, all the following nerves can be anesthetized using a perivascular injection EXCEPT:
    (a) Interscalene brachial plexus
    (b) Axillary brachial plexus

(c) Median nerve at the elbow
(d) Ulnar nerve at the wrist

Answers:

1. b
2. d
3. d
4. c
5. b
6. d
7. a
8. b
9. c
10. a
11. a
12. b
13. c
14. d
15. a

References

1. Boezaart AP. That which we call a rose by any other name would smell as sweet – and its thorns would hurt as much. Reg Anesth Pain Med. 2009;34:3–7.
2. Rettig HC, Gielen MJM, Jack NTM, Boersma E, Klein J. A comparison of the lateral and posterior approach for brachial plexus block. Reg Anesth Pain Med. 2006;31:119–26.
3. Dewees JL, Schultz CT, Wilkerson FK, Kelly JA, Biegner AR, Pellegrini JE. Comparison of two approaches to brachial plexus anesthesia for proximal upper extremity surgery: interscalene and intersternocleidomastoid. AANA J. 2006;74:201–6.
4. Deleuze A, Gentili M, Marret E, Lamonerie L, Bonnet F. A comparison of a single-stimulation lateral infraclavicular plexus block with a triple-stimulation axillary block. Reg Anesth Pain Med. 2003;28:89–94.
5. Koscielniak-Nielsen ZJ, Rasmussen H, Hesselbjerg L, Nielsen TP, Gurkan Y. Infraclavicular block causes less discomfort than axillary block in ambulatory patients. Acta Anaesth Scand. 2005;49:1030–4.
6. Minville V, Fourcade O, Idabouk L, et al. Infraclavicular brachial plexus block versus humeral block in trauma patients: a comparison of patient comfort. Anesth Analg. 2006;102:912–6.
7. Tran DQH, Russo GL, Munoz L, Zaouter C, Finlayson RJ. A prospective, randomized comparison between ultrasound-guided supraclavicular, infraclavicular and axillary brachial plexus blocks. Reg Anesth Pain Med. 2009;34:366–71.
8. Liguori GA, Zayas VM, YaDeau JT, et al. Nerve localization techniques for interscalene brachial plexus blockade: a prospective, randomized comparison of mechanical paresthesia versus electrical stimulation. Anesth Analg. 2006;103:761–7.
9. Smith BL. Efficacy of a nerve stimulator in regional anesthesia; experience in resident training programme. Anaesth. 1976;31:778–82.

10. Boezaart A, de Beer J, du Toit C, van Rooyen K. A new technique of continuous interscalene nerve block. Can J Anesth. 1999;46:275–81.
11. Kapral S, Greher M, Huber G, et al. Ultrasonographic guidance improves the success rate of interscalene brachial plexus blockade. Reg Anesth Pain Med. 2008;33:253–8.
12. Liu SS, Zayas VM, Gordon MA, et al. A prospective, randomized, controlled trial comparing ultrasound versus nerve stimulator guidance for interscalene block for ambulatory shoulder surgery for postoperative neurological symptoms. Anesth Analg. 2009;109:265–71.
13. Sites BD, Neal JM, Chan V. Ultrasound in regional anesthesia: where should the "focus" be set? Reg Anesth Pain Med. 2009;34:531–3.
14. Urmey WF, Talts KH, Sharrock NE. One hundred percent incidence of hemidiaphragmatic paresis associated with interscalene brachial plexus anesthesia as diagnosed by ultrasonography. Anesth Analg. 1991;72:498–503.
15. Urmey WF, Gloeggler PJ. Pulmonary function changes during interscalene brachial plexus block: effects of decreasing local anesthetic injection volume. Reg Anesth. 1993;18:244–9.
16. Urmey WF, Grossi P, Sharrock N, Stanton J, Gloeggler PJ. Digital pressure during interscalene block is clinically ineffective in preventing anesthetic spread to the cervical plexus. Anesth Analg. 1996;83:366–70.
17. Bennani SE, Vandenabele-Teneur F, Nyarwaya JB, Delecroix M, Krivosic-Horber R. An attempt to prevent spread of local anesthetic to the phrenic nerve by compression above the injection site during interscalene brachial plexus block. Eur J Anaesth. 1998;15:453–6.
18. Sala-Blanch X, Lazaro JR, Correa J, Gomez-Fernandez M. Phrenic nerve block caused by interscalene brachial plexus block: effects of digital pressure and a low volume of local anesthetic. Reg Anesth Pain Med. 1999;24:231–5.
19. Al-Kaisy AA, Chan VWS, Perlas A. Respiratory effects of low-dose bupivacaine interscalene block. Br J Anaesth. 1999;82:217–20.
20. Riazi S, Carmichael N, Awad I, Hotby RM, McCartney CJL. Effect of local anesthetic volume (20 vs 5 mL) on the efficacy and respiratory consequences of ultrasound-guided interscalene brachial plexus block. Br J Anaesth. 2008;101:549–56.
21. Boezaart AP, de Beer JF, Nell ML. Early experience with continuous cervical paravertebral block using a stimulating catheter. Reg Anesth Pain Med. 2003;28:406–13.
22. Brown DL, Cahill DR, Bridenbaugh D. Supraclavicular nerve block: anatomic analysis of a method to prevent pneumothorax. Anesth Analg. 1993;76:530–4.
23. Franco CD, Domashevich V, Voronov G, Rafizad AB, Jelev TJ. The supraclavicular block with a nerve stimulator: to decrease or not to decrease, that is the question. Anesth Analg. 2004;98:1167–71.
24. Soares LG, Brull R, Lai J, Chan VW. Eight ball, corner pocket: the optimal needle position for ultrasound-guided supraclavicular block. Reg Anesth Pain Med. 2007;32:94–5.
25. Renes SH, Spoormans HH, Gielen MH, Rettig HC, van Geffen JG. Hemidiaphragmatic paresis can be avoided in ultrasound-guided supraclavicular brachial plexus block. Reg Anesth Pain Med. 2009;34:595–9.
26. Duggan E, El Beheiry H, Perlas A, et al. Minimum effective volume of local anesthetic for ultrasound-guided supraclavicular brachial plexus block. Reg Anesth Pain Med. 2009;34:215–8.
27. Knoblanche GE. The incidence and aetiology of phrenic nerve blockade associated with supraclavicular brachial plexus block. Anaesth Intens Care. 1979;7:346–9.
28. Rodriguez J, Taboada M, Oliveira J, et al. Single-stimulation of the posterior cord is superior to dual nerve stimulation in a coracoid block. Acta Anaesthesiol Scand. 2010;54:241–5.
29. Tran DQH, Bertini P, Zaouter C, Munoz L, Finlayson RJ. A prospective, randomized comparison between single- and double-injection ultrasound-guided infraclavicular brachial plexus block. Reg Anesth Pain Med. 2010;35:16–21.
30. Desgagnes MC, Levesque S, Dion S, et al. A comparison of a single or triple injection technique for ultrasound-guided infraclavicular block: a prospective randomized controlled study. Anesth Analg. 2009;109:668–72.

31. Sauter AR, Dodgson MS, Stubhaug A, Halstensen AM, Klaastad O. Electrical nerve stimulation or ultrasound guidance for lateral sagittal infraclavicular blocks: a randomized, controlled, observer-blinded, comparative study. Anesth Analg. 2008;106:1910–5.
32. Taboada M, Rodriguez J, Amor M, et al. Is ultrasound guidance superior to conventional nerve stimulation for coracoid infraclavicular brachial plexus block? Reg Anesth Pain Med. 2009;34:357–60.
33. Brull R, Lupu M, Perlas A, Chan VWS, McCartney CJL. Compared with nerve stimulation, ultrasound guidance shortens the time for infraclavicular block performance. Can J Anesth. 2009;56:812–8.
34. Dingemans E, Williams SR, Arcand G, et al. Neurostimulation in ultrasound-guided infraclavicular block: a prospective randomized trial. Anesth Analg. 2007;104:1275–80.
35. Gurkan Y, Tekin M, Acar S, Solak M, Toker K. Is nerve stimulation needed during an ultrasound-guided lateral sagittal infraclavicular block? Acta Anaesthesiol Scand. 2010;54:403–7.
36. Raj PP, Montgomery SJ, Nettles D, Jenkins MT. Infraclavicular brachial plexus block – a new approach. Anesth Analg. 1973;52:897–904.
37. Wilson JL, Brown DL, Wong GY, et al. Infraclavicular brachial plexus block: parasagittal anatomy important to the coracoid technique. Anesth Analg. 1998;87:870–3.
38. Stadlmeyer W, Neubauer J, Finkl RO, Groh J. Unilateral phrenic paralysis after vertical infraclavicular plexus block [German]. Anaesthetist. 2000;49:1030–3.
39. Crews JC, Gerancher JC, Wellers RS. Pneumothorax after coracoid infraclavicular brachial plexus block. Anesth Analg. 2007;105:275–7.
40. Tran DQH, Clemente A, Doan J, Finlayson RJ. Brachial plexus blocks: a review of approaches and techniques. Can J Anesth. 2007;54:662–74.
41. Sia S, Bartoli M. Selective ulnar nerve localization is not necessary for axillary brachial plexus block using a multiple nerve stimulation technique. Reg Anesth Pain Med. 2001;26:12–6.
42. Sia S. A comparison of injection at the ulnar and the radial nerve in axillary block using triple stimulation. Reg Anesth Pain Med. 2006;31:514–8.
43. Sia S, Lepri A, Magherini M, Doni L, Di Marco P, Gritti G. A comparison of proximal and distal radial nerve motor responses in axillary block using triple stimulation. Reg Anesth Pain Med. 2005;30:458–63.
44. Chan VWS, Perlas A, McCartney CJL, Brull R, Xu D, Abbas S. Ultrasound guidance improves success rate of axillary brachial plexus block. Can J Anesth. 2007;54:176–82.
45. Casati A, Danelli G, Baciarello M, et al. A prospective, randomized comparison between ultrasound and nerve stimulation guidance for multiple injection axillary brachial plexus block. Anesthesiology. 2007;106:992–6.
46. O'Donnell BD, Iohom G. An estimation of the minimum anesthetic volume of 2% lidocaine in ultrasound-guided axillary brachial plexus block. Anesthesiology. 2009;111:25–9.
47. 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.
48. Peng PWH, Wiley MJ, Liang J, Bellingham GA. Ultrasound-guided suprascapular nerve block: a correlation with fluoroscopic and cadaveric findings. Can J Anesth. 2010;57:143–8.
49. Fredrickson MJ, Ball CM, Dagleish AJ, Stewart AW, Short TG. A prospective randomized comparison of ultrasound and neurostimulation as needle end points for interscalene catheter placement. Anesth Analg. 2009;108:1695–700.
50. Dhir S, Ganapathy S. Comparative evaluation of ultrasound-guided continuous infraclavicular brachial plexus block with stimulating catheter and traditional technique: a prospective-randomized trial. Acta Anaesthesiol Scand. 2008;52:1158–66.
51. Mariano ER, Loland VJ, Sandhu NS, et al. A trainee-based randomized comparison of stimulating interscalene perineural catheter with a new technique using ultrasound guidance alone. J Ultrasound Med. 2010;29:329–36.
52. Mariano ER, Loland VJ, Bellars RH, et al. Ultrasound guidance versus electrical stimulation for infraclavicular brachial plexus perineural catheter insertion. J Ultrasound Med. 2009;28:1211–8.

53. Ficarotta MR, Morey TE, Boezaart AP. Does "Opening the Perineural Space" before stimulating catheter placement for continuous nerve block add value in clinical practice? Reg Anesth Pain Med. 2010;35:245–8.
54. Tran DQH, De La Cuadra Fontaine JC, Chan SY, Kovarik G, Asenjo JF, Finlayson RJ. Coiling of stimulating perineural catheters. Anesthesiology. 2007;106:189–90.
55. Sauter AR, Smith HJ, Stubhaug A, et al. Use of magnetic resonance imaging to define the anatomical location closest to all three cords of the infraclavicular brachial plexus. Anesth Analg. 2006;103:1574–6.
56. Tran DQH, Charghi R, Finlayson RJ. The "Double Bubble" sign for successful infraclavicular brachial plexus blockade. Anesth Analg. 2006;103:1048–9.
57. Loubert C, Williams SR, Helie F, Arcand G. Complication during ultrasound-guided regional block: accidental intravascular injection of local anesthetic. Anesthesiology. 2008;108:759–60.

Suggested Reading

Tran DQH, Clemente A, Doan J, Finlayson RJ. Brachial plexus blocks: a review of approaches and techniques. Can J Anesth. 2007;54:662–74.
Neal JM, Gerancher JC, Hebl JR, Ilfeld BM, McCartney CJL, Franco CD, et al. Upper extremity regional anesthesia- essentials of our current understandings 2008. Reg Anesth Pain Med. 2009;34:134–70.
McCartney CJL, Lin L, Shastri U. Evidence basis for the use of ultrasound for upper-extremity blocks. Reg Anesth Pain Med. 2009;35:S10–5.