▼ Review Article

Ultrasound in the Practice of Brachial Plexus Anesthesia

Jose De Andrés, M.D., Ph.D., and Xavier Sala-Blanch, M.D.

Success of regional anesthesia technique is dependent upon the correct positioning of the local anesthetic solution near the desired nerve trunk.[1,2] Since the development of regional anesthesia, various mechanical aids have been used for nerve detection, including radiography[3] and peripheral nerve stimulation,[4,5] both with the aim of verifying needle location and increasing the success rate.[2] Other methods for facilitating blocks include Doppler techniques,[6] sympathetic-galvanic reflexes and thermography,[7-10] photoplethysmography,[11] and other physical aids.[12]

Imaging techniques seem most directly able to identify nerve structures and facilitate the performance of brachial plexus blocks. Radiography (computed axial tomography [CAT]) has already been successfully used to help locate and insert catheters near the brachial plexus.[13] In contrast, ultrasound (US) is currently the only imaging technique allowing anatomic assessment of the brachial plexus and/or adjacent structures at the patient bedside and hence also in the operating room.[14] Many believe US can identify plexus structures, and coupled with topographic anatomical knowledge, ease brachial plexus blocks.[14,15] However, the costs of the US devices continue to limit widespread application of this approach. Gradual cost reduction as a result of technological advancement, together with a reduction in the block complications will, we believe, make the US technique increasingly attractive for anesthesiologists in their practices.

The present review provides some basic details of ultrasonographic technique, with emphasis on anatomical knowledge important for US of the brachial plexus. Finally, a brief analysis of the literature about regional block and US is provided.

Facts About US

Physical Fundaments of Ultrasonography

US is defined as sound waves above a frequency of 20,000 Hz. These waves are generated when an alternating current is applied to a material possessing piezoelectric properties, i.e., the capability of vibrating and converting electric energy into sound. Such materials are, in turn, able to reconvert sound waves into current and thus behave as both an emitter and receptor. The characteristics of the sound waves are shown in Table 1. Sound transmission requires the presence of a conducting medium, and the velocity of transmission through the medium depends on its acoustic impedance, which is, in turn, dependent on the density of the conducting medium. The average conduction velocity of sound in human body tissues is 1,540 m/sec versus 31 m/sec in air and 4,080 m/sec in cortical bone. When 2 materials with different acoustic impedances are in contact, an interface effect occurs between them. Accordingly, when the sound waves reach 1 interface, some of them are reflected back to the emitting transducer. This reflectivity phenomenon (proportional to the difference in acoustic impedance between the 2 materials conforming the interface), in turn, determines the resulting US image. Thus, greater reflectivity implies an increased signal intensity, and the corresponding US image is therefore brighter (or more echogenic), while diminished reflectivity implies a weaker signal intensity and a darker (or less echogenic) image.

As the sound waves travel through a medium, their amplitude gradually diminishes, a phenomenon known as beam attenuation. The latter is, in

From the Department of Anesthesia, Valencia University Medical School, Pain Management Center, Department of Anesthesiology and Critical Care, Valencia University General Hospital (J.D.) and the Servicio de Anestesiología y Reanimación, Hospital Clínic de Barcelona, Universidad de Barcelona (X.S-B.), Barcelona, Spain.

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Reprint requests: Jose De Andrés, M.D., Ph.D., Department of Anesthesiology and Critical Care, Valencia University General Hospital, Avda. Tres Cruces s/n, 46014 Valencia, Spain. E-mail: deandres_jos@gva.es

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Table 1. Characteristics of US

Velocity	
	Wave displacement per unit time; dependent upon the medium through which the sound travels (unit: m/s). Biological tissues exhibit an average velocity of 1,540 m/s.
Wavelength	
	Distance covered in the course of a single cycle in the direction of propagation of the wave (unit: mm).
Period	
	Time elapsed to completion of a single wave cycle (unit: seconds).
Frequency	
	Number of periods/second (unit: Hz).
Amplitude	
	Corresponds to square root of wave energy.

turn, dependent upon the density of the medium (tissues), the US wavelength, and the heterogeneity of the medium (i.e., its number and type of interfaces). However, echographs compensate for this effect by generating images dependent upon reflection rather than on beam attenuation. This is achieved via the so-called time-gain compensation (TGC) curve, which constitutes the electronic mechanism by which amplification at reception is achieved of the attenuation produced by sound propagation as a function of the depth from which the signal arises, the exploration frequency, and the study tissue. TGC consists of correcting the attenuation effects, which are proportional to echo depth, since the latter lose increasing energy with the depth traveled. Accordingly, TGC allows increased amplification of the deeper echoes.

US Images

The images obtained on the echograph screen are thus seen to be dependent upon reflectivity, i.e., the changes in acoustic impedance found along the trajectory of the sound beam.[16,17] The resulting images can reflect contours, i.e., areas with different acoustic impedances, which can be due to an anatomical separation, either a wall (separating 2 tissues with distinct acoustic impedances) or a partition (2 compartmented fluid accumulations) or a separation between 2 areas of marked acoustic impedance. Other images are, in turn, attributable to the transmitting tissue itself and include fluids (which transmit sound perfectly, thereby generating no echoes, and are characterized by posterior enhancement with lateral shadows) and solids, featuring disperse echoes (sound attenuation occurs) and exhibiting either a homogeneous or heterogeneous pattern. Lastly, consideration is required of the acoustic shadow effect occurring when the sound waves cross interface with marked differences in acoustic impedance, such as bone or air. The echographic features of the different tissues seen in the US evaluation of soft tissues, such as those involved in our study, are given in Table 2. The image of the nerves along their longitudinal axis is that of hyperechogenic tubular structures, while along their transverse axis, the pattern corresponds to circular or oval structures with a gross punctate internal pattern; both image types are similar to those produced by tendons, although involving lesser echogenicity. In practical terms, however, the situation is different. In effect, the nerve trunks of the brachial plexus are typically identified as hypodense echographic images attributable to the presence of artifacts. Such artifacts are false images observed with US and are usually attributable to technical deficiencies involving either a poor anatomical knowledge of the zone, defective positioning of the transducer and/or patient, or the existence of anatomical particularities that make the study difficult. Nevertheless, an artifact of particular interest in the context of the present study is anisotropy, which is characterized by the identification of a hypoechoic image due to total US beam reflection caused by tangential contact at the interface (Fig 1), a phenomenon that can be explained by the topographic anatomical features of the zone in which the plexus is found.

Doppler Effect

The Doppler effect is a wave frequency variation between the original frequency and its value at reception. In this context, the frequency at reception decreases when the emitting source moves away from the receptor and increases when it moves towards the latter. In practical terms, this property is used to measure the velocity of blood displacement within the vessels. To apply the Doppler effect, the emitting-receptor head must be able to identify the frequency of the received US waves and compare it with the frequency of the emitted

Table 2. Echographic Images of the Tissues Identifiable During US Study of the Brachial Plexus Territories

Tissues	US Image	Artifacts
Venous vessels	Compressible anechoic	
Arterial vessels	Pulsatile anechoic	
Fat	Hypoechoic	
Muscle		
Perimysium	Hyperechoic	
Muscle tissue	Hypoechoic	
Tendons	Hyperechoic	Anisotropy (hypoechoic)
Bone	Very hyperechoic fine line	
Cartilage	Anechoic fine band	
Nerves	Hyperechoic	Anisotropy (hypoechoic)

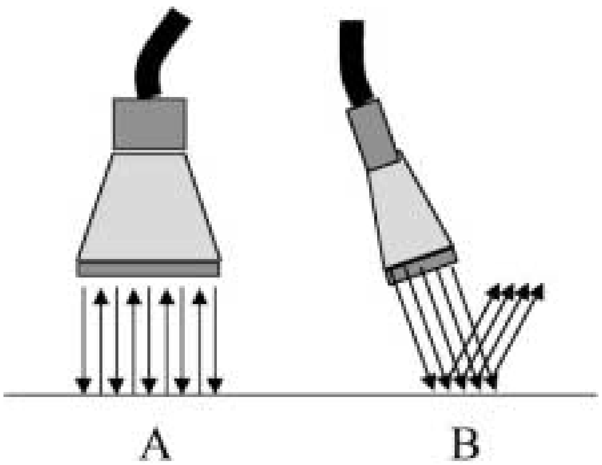

Fig 1. Schematic representation of the concept of reflection and explanation of anisotropy. The echoes reflected following contact with an interface are returned to the transducer (A) and are identified as corresponding to a hyperechogenic structure; however, if contact is not transversal, the reflected echoes are not returned to the transducer, and a hypoechogenic image results (B). This artifact is known as anisotropy.

waves; the Doppler effect is generated when these 2 frequencies differ. If the US system is equipped with this technical option, it becomes possible to identify vascular structures, this being an important advantage in application to the anatomical zone of the brachial plexus.

Facts About Brachial Plexus Anatomy

An essential requirement for applying US to the brachial plexus is detailed knowledge of the anatomical zone surrounding the plexus, including both classical topographic anatomy (anatomical planes) and cross-sectional anatomy. Topographic anatomy allows us to identify the different structural layers related to and in proximity to the plexus, while cross-sectional anatomy facilitates learning and identification of the structures seen on the echograph screen.

The different brachial plexus anesthetic techniques relate to distinct anatomical zones that must be understood to take advantage of the technology. The brachial plexus runs from its origin in the neck to its distal nerves in the arm, traversing 3 anatomically differentiated zones that, in turn, correspond to the different approaches to brachial plexus anesthesia: the supraclavicular region (posterior triangle of the neck), the infraclavicular region (anterior shoulder zone), and the axillary region (root of the arm).

Supraclavicular Region (Posterior Triangle of the Neck)

Topographic Anatomy. The posterior triangle of the neck has well-described borders corresponding to the collarbone at the base, the posterior margin of the sternocleidomastoid muscle anteriorly, and the trapezius muscle posteriorly, creating the supraclavicular fossa.

The supraclavicular fossa is covered by skin and subcutaneous tissue and the supraacromial and supraclavicular cutaneous branches of the superficial cervical plexus. A second layer consists of the fascia or superficial cervical aponeurosis, encompassing the muscles defining the limits of the supraclavicular region, i.e., the sternocleidomastoid and trapezius muscles. A third anatomical layer, in turn, consists of the middle cervical aponeurosis, which envelops the omohyoid muscle that crosses the supraclavicular region and can easily be identified by palpation. The external jugular vein is, in turn, found on its surface.

The deep zone presents the deep cervical aponeurosis, which constitutes the continuation of the prevertebral fascia. Within this region are anatomic relationships that must be understood for correct performance of brachial anesthesia. The anterior scalene muscle originates from the anterior tubercles of the transverse processes of the fourth, fifth, and sixth cervical vertebra and insert onto Lisfranc's tubercle on the anterior aspect of the first rib. At its insertion, the anterior scalene muscle separates 2 important vascular structures, the subclavian artery and vein, respectively, located posterior and anterior to the muscle.

Cephaloposterior to the subclavian artery is found the brachial plexus, which rests upon the anterior belly of the middle scalene muscle. The middle scalene muscle originates in the posterior tubercles of the transverse processes of the first 4 to 5 cervical vertebra and inserts in the external margin of the first and second ribs. The posterior scalene muscle, in turn, originates in the posterior tubercles of the fourth, fifth, and sixth cervical vertebras and inserts on the external aspect of the second and third ribs.

Important vascular relationships are found in this anatomic region. The subclavian artery emerges to the right from the brachiocephalic trunk and from the left of the aortic arch. The subclavian artery is a basic reference for US-guided brachial plexus anesthesia. It, in turn, gives rise to the vertebral artery, which penetrates the intertransverse foramina (from the sixth cervical vertebra) located anterior to the path of the spinal nerves through the neural foramen, and which is of interest when performing interscalene anesthetic techniques.

In the supraclavicular region, the external collaterals of the subclavian artery (i.e., the transverse cervical and suprascapular arteries) are important in relation to supraclavicular anesthesia.

Cross-Sectional Anatomy. The cross-sectional anatomical features depend on the point of US imaging, which is, in turn, dependent upon the anesthetic technique performed. When adopting an interscalene anesthetic approach, attention focuses on the neck, and a horizontal section is indicated; in comparison, a supraclavicular technique requires a sagittal section of the supraclavicular region.

A transverse anatomical section at C6 level allows identification of the sternocleidomastoid muscle, with the common carotid artery and internal jugular vein found medial to the muscle. Posterior to these vessels lies the scalene musculature, the anterior scalene muscle positioned posterior to the vessels and the middle and posterior scalene muscles located posteriorly, forming a single muscle mass.

Located between the scalene muscles are a series of rounded or oval nodules corresponding to the nerve roots and/or trunks of the brachial plexus. Medial to the interscalene zone lies the transverse process of C6, with the vertebral artery and vein located anterior to the latter (Fig 2, A1 and B1).

A sagittal section at supraclavicular fossa level allows identification of the collarbone, with the subclavian muscle caudad to the bone and the subclavian vein on the first rib. In a more anterior plane lies the omohyoid muscle and subclavian artery. Finally, the brachial plexus lies cephalopostero to the artery (Fig 3, A1 and B1).

Intraclavicular Region (Anterior Axillary Wall)

Topographic Anatomy. The infraclavicular region has well-defined limits corresponding to the collarbone superiorly, the inferior margin of the greater pectoral muscle below, the deltopectoral sulcus externally, and the vertical traced from the center of the collarbone to the inferior margin of the greater pectoral muscle internally.

The infraclavicular region is covered by skin and subcutaneous tissue. A second layer, in turn, consists of the superficial aponeurosis that superficially covers the greater pectoral muscle and extends towards the deltoid muscle through the deltopectoral sulcus. A third muscle layer contains the greater pectoral muscle, while a fourth anatomical plane comprises the middle axillary aponeurosis or clavipectoral fascia, which envelops the subclavian muscle and extends towards the pectoralis minor muscle to the axillary fascia. In the region deep to the clavipectoral fascia lies the axillary fossa, the previously described zone representing the anterior wall of the latter. The axillary fossa, in turn, contains the axillary neurovascular bundle. The most medial lying structure of the bundle is the axillary vein, followed by the axillary artery and, more laterally, by the 3 fascicles of the brachial plexus. On reaching the area of the pectoralis minor muscle, the neurovascular bundle is more deeply placed, and the nerve fascicles become distributed around the artery. The axillary vein is formed by the confluence of the brachial veins, and over its axillary course, receives the cephalic vein at the level of the deltopectoral triangle. The axillary artery, in turn, emits the thoracoacromial, long thoracic, subscapular, and humeral circumflex arteries.

Cross-Sectional Anatomy. The sectional anatomy in the parasagittal plane of the middle infraclavicular region corresponds to the anterior wall of the axillary fossa. Accordingly, the collarbone and pectoralis major muscle are found anteriorly, followed more medially by the subclavian muscle, the clavipectoral fascia, and the pectoralis minor muscle. Within this musculoaponeurotic wall, we can identify the neurovascular bundle, the vein lying caudad, the artery medially, and the secondary trunks of the brachial plexus more cranially. If the section is centered at distal infraclavicular level (i.e., at subacromial level) (Fig 4, A1 and B1), the acromion is identified with the insertion of the pectoralis minor muscle and the neurovascular bundle located immediately posterior to the latter. At this level, the secondary trunks and terminal branches of the brachial plexus have become distributed around the axillary artery.

Axillary Region (Root of the Arm)

Topographic Anatomy. In the region of the arm, the neurovascular bundle is distributed in the internal bicipital sulcus, which separates the flexor musculature of the arm (biceps) from the extensor musculature (triceps). A first layer consists of the skin and subcutaneous tissue, while a second layer contains the superficial aponeurosis or fascia, which superficially covers the medial bicipital sulcus and continues with the aponeurosis of the flexor and extensor muscles of the arm. Below the superficial aponeurosis and within the bicipital sulcus lies the neurovascular bundle, with the vein and nerves lying more superficially than the brachial artery. Below the superficial fascia, we can identify the muscle plane, consisting at ventral level (flexor musculature) of the inferior insertions of the deltoid muscle and the biceps of the arm; the coraco-

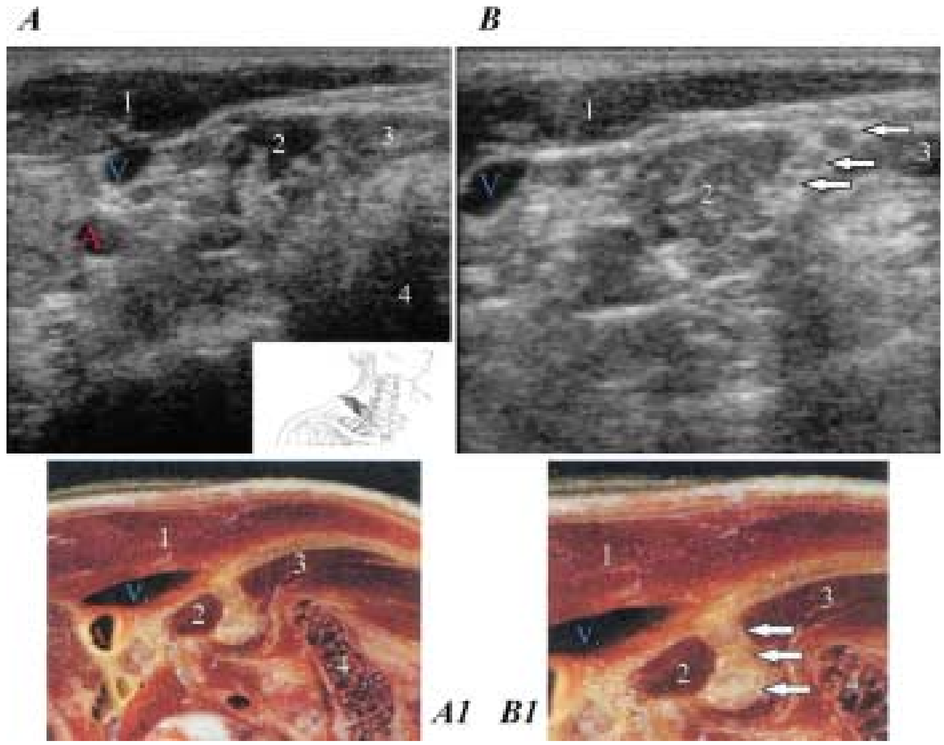

Fig 2. Interscalene transverse cross-section. Transverse cross-section at C6 level, identifying the different muscles and vascular structures in the neck region (A), showing 3 hypodense nodular structures located between the scalene muscles (arrows, B) corresponding to the trunks of the brachial plexus. The anatomical sections facilitate identification of the anatomical images. (1) Sternocleidomastoid muscle; (2) anterior scalene muscle; (3) middle scalene muscle; (4) C6 transverse process; (A) carotid artery; and (V) internal jugular vein. White arrows: trunks of the brachial plexus.

brachial and anterior brachial muscles lie more deeply. In the posterior region (extensor musculature) of the arm, we find a single muscle plane with the 3 portions of the triceps muscle. Finally, the humerus is located in the deepest zone.

Cross-Sectional Anatomy. The sectional anatomy of the upper third of the arm allows us to identify the internal bicipital sulcus (a hyperdense structure) with the two humeral vessels—the vein lying superficially and the artery running internal

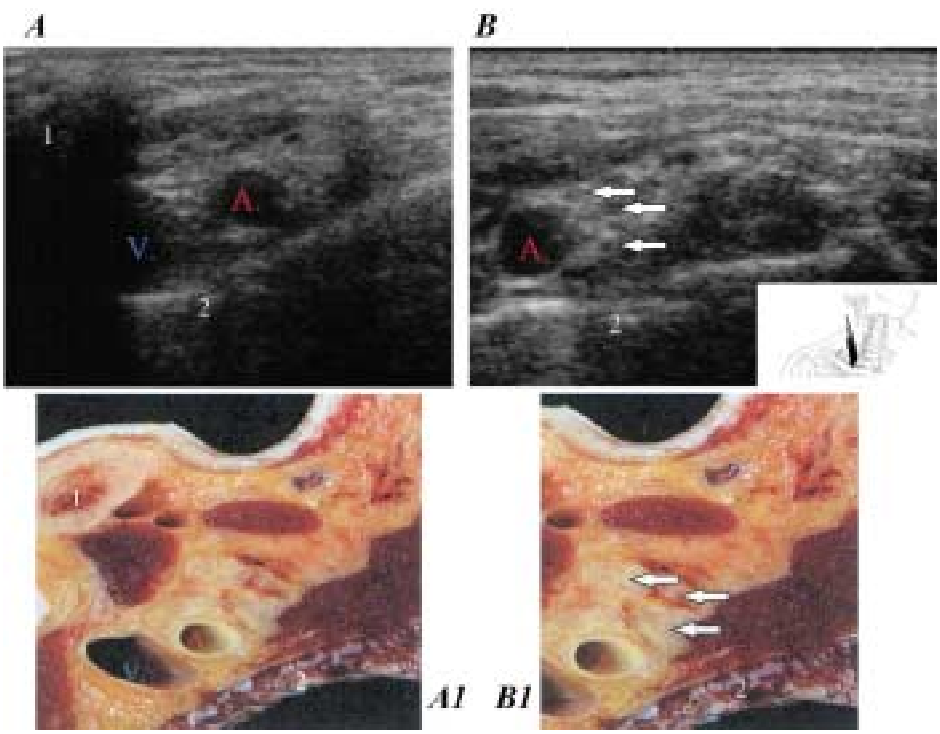

Fig 3. Supraclavicular sagittal cross-section. Sagittal cross-section at the level of the first rib, showing the different vascular structures of the supraclavicular region (A) and identifying hypodense nodular structures in the superoposterior portion of the subclavian artery, corresponding to the divisions of the brachial plexus (arrows, B). The anatomical sections facilitate identification of the US images (A1, B1). (1) Collarbone; (A) subclavian artery; and (V) subclavian vein. White arrows: divisions of the brachial plexus.

to the vein. At this level the terminal branches of the brachial plexus have begun to separate and distribute towards their respective innervation territories. The radial nerve is located in the depth of the sulcus, while the median and ulnar nerves continue accompanying the artery in its more superficial portion.

Facts About Ultrasonographic Anatomy of the Brachial Plexus

The interscalene techniques are performed in the cervical region, in the interscalene groove. US evaluation of the neck region requires the use of high-resolution devices, due to the complexity of its anatomical structures. Availability of the Doppler effect, in turn, allows one to identify the vascular structures and thus facilitate the location of the varied anatomical spaces. The probe or transducer must offer performance in the 7.5 to 10 MHz range to evaluate and identify the important superficial muscular and vascular landmarks. The global anatomy can be identified in the sectional or transverse US study at C6 level (Fig 2A and B). Superficially, we identify the sternocleidomastoid muscle (its clavicular belly), while deep to the latter, we have the internal jugular vein and carotid artery, as well as the anterior and middle-posterior interscalene muscles. Between the middle and anterior scalene muscles lies a separation with fatty-tissue US features in which a series of hypodense nodules are seen, corresponding to the trunks of the brachial plexus.[15] More deeply lies an acoustic shadow effect (bone pattern) attributable to the transverse process of C6. Small cranial or caudad displacements of the probe cause this shadow to disappear, and the vertebral vessels can be identified with the help of the Doppler effect.

The supraclavicular techniques, in turn, focus on the supraclavicular fossa, where the superior, middle, and inferior primary trunks divide into their anterior and posterior branches. The plexus runs superficially at this level, and high-frequency transducers are thus needed (10 MHz) to identify the structures. Technical difficulties are encountered in studying the supraclavicular region due to the presence of the supraclavicular depression, which complicates both manipulation of the probe and needle puncture. Finally, and although the important primary trunks of the brachial plexus are easily identified between the scalene muscles in the interscalene space, in the supraclavicular zone, the plexus is more difficult to locate. Although color Doppler pulsing is not required to identify the subclavian artery, it greatly facilitates identification of the brachial plexus by allowing us to differentiate the nerves (hypoechogenic in the absence of Doppler effect) from the arterial and venous branches found in the zone (hypoechogenic with Doppler effect). The ultrasonographic anatomy of the supraclavicular region is shown in Fig 3A and B.

The infraclavicular techniques are performed over the pectoral region. The ultrasonographic evaluation of this region is straightforward, due to the simplicity of its anatomical structures. The Doppler option, in turn, facilitates identification of the vascular structures, particularly the divisions of the axillary vessels, thereby contributing to minimizing vascular puncture, the latter being the most frequent complication associated with the infraclavicular techniques.[18] In view of the increased depth at which the brachial plexus is found at this level with respect to other techniques, the transducer may be of lower frequency (5 to 7.5 MHz).

The proximal infraclavicular techniques are performed over the midpoint of the collarbone. At this point, the plexus lies relatively superficial (3 to 5 cm) and is located deep to the subclavian muscle and clavipectoral fascia, resting upon the first digitation of the serratus muscle. The location of the plexus with respect to its most important reference structure (the axillary artery) is cranial and external. At this level, the anterior and posterior divisions group to form the secondary trunks. Doppler pulsing allows us to identify the thoracoacromial branch of the axillary artery, which originates in this region. The plexus is thus distributed in the superointernal zone of the artery.

The distal or coracoid infraclavicular techniques are performed in the distal region of the infraclavicular plexus, at the point where the end-nerves are forming. The anatomical features correspond to the axillary neurovascular bundle, which runs deep to the pectoralis minor muscle. At this point, the depth of the neurovascular bundle is 4 to 5 cm, thus requiring lower frequency probes (3.5 to 7.5 MHz). At this level (Fig 4A and B), one can identify the thick muscle space of the pectoralis major and minor muscles (separated by a hyperechogenic band corresponding to the perimysium). The terminal branches of the brachial plexus are located at this level near the axillary artery.

The axillary techniques are performed in the region of the internal bicipital sulcus. US evaluation requires the use of high-resolution and high-frequency systems (10 MHz) due to the superficial distribution of the neurovascular elements (1 to 2 cm). Color Doppler provides little additional information, since the vascular structures are easily identifiable and palpable at this level. The ultrasonographic anatomy can be seen in Fig 5A and B.

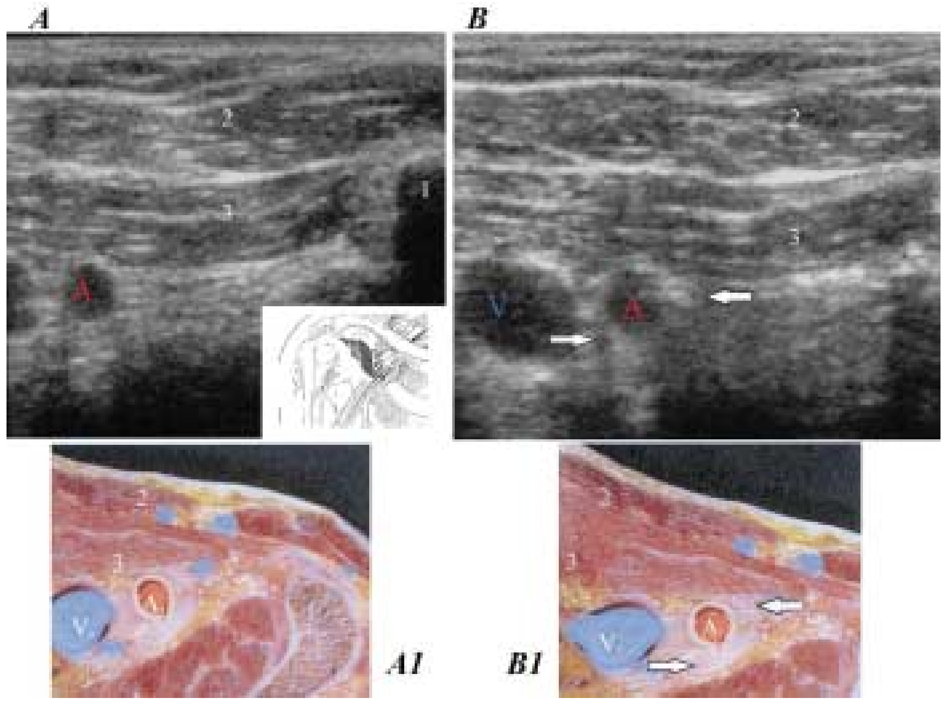

Fig 4. Infraclavicular sagittal cross-section. Sagittal cross-section corresponding to the pectoral zone (anterior wall of the axilla), showing the different muscles and vascular structures in the region (A); hypodense nodular structures are seen around the axillary artery (A) (arrows, B), corresponding to the trunks of the brachial plexus. The anatomical sections facilitate identification of the US images (A1, B1). (1) Coracoid process of the scapula; (2) pectoralis major muscle; (3) pectoralis minor muscle; (A) axillary artery; and (V) axillary vein. White arrows: trunks of the brachial plexus.

US-Guided Brachial Plexus Anesthesia

Our experience has been accumulated in the context of brachial plexus block. We have used a Toshiba Model ECO CEE device (Toshiba Corp, Tokyo, Japan), using a 4-cm linear, 8-MHz transducer (approximate cost, $50,000).

The brachial plexus in the supraclavicular region is located at scant depth; high-frequency transducers (7.5 to 10 MHz) are therefore required to obtain quality images at this level. Similar considerations apply to the axillary region, where the plexus likewise runs superficially. Only at infraclavicular level and/or in very obese patients should lower frequency probes (5 MHz) be used.

Although the use of linear transducers is advisable, since they facilitate anatomical identification, the associated risk of artifacts is greater because of technical difficulties related to the topographical characteristics of the region in which the plexus is found.

The pressure exerted by the transducer upon the skin produces a degree of surface depression, result-

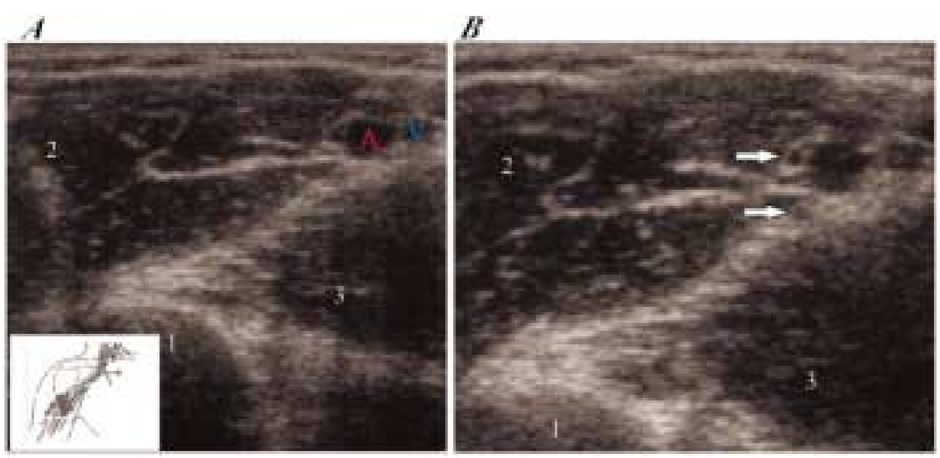

Fig 5. Axillary transverse cross-section. Transverse cross-section corresponding to the proximal zone of the arm, showing the different muscles and vascular structures (A), and identifying hypodense nodular structures around the axillary artery (A) (arrows, B), corresponding to the end-nerves of the brachial plexus. (1) Humerus; (2) coracobrachial muscle; (3) triceps muscle of the arm; (A) humeral artery; and (V) humeral vein. White arrows: end-nerves of the brachial plexus.

ing in a lesser than expected distance to the plexus, which may complicate visualization of the superficial veins due to collapsing of the vascular lumen. This fact should be taken into account and may be used to distinguish veins from arteries (although the Doppler effect is better suited for this purpose).

The plexus neural structures are easily identified at the interscalene and supraclavicular level, where they are compactly located in a concrete zone, consist of thick primary nerve trunks, and present anatomical references or landmarks that are easily established by US; these elements are, in turn, easily visualized with the newer ultrasonographic systems operating at medium to high frequencies. However, at infraclavicular and axillary levels, the brachial plexus begins to diverge from the axillary and humeral arteries and identification of the specific nerves becomes more difficult, with the added requirement of high-performance ultrasonographic transducers. In contrast, anatomical knowledge and the easy identification of the arterial vessels greatly facilitates the anesthetic techniques.

Ultrasonographically-guided puncture can be facilitated by using guides connected to the transducer. This measure makes puncture easier, particularly at infraclavicular level, due to the large visual margin afforded; however, imaging may prove difficult in the supraclavicular space. In our experience, puncture assisted by US is most easily performed without guides, under direct visualization, and using neurostimulation needles, thus allowing use of the combined US and neurostimulation technique. During puncture the advance of the needle through the desired anatomical region can be followed. In this sense, direct dynamic visualization is of help in identifying needle advancement, while in contrast, static images pose identification difficulties (exposed photographs). The use of marked needles to determine depth would also be of utility during puncture guided by US.

To perform the US-guided interscalene anesthetic technique (Fig 6), the trunks of the brachial plexus must be identified, inserting the puncture needle in the interscalene groove under direct visualization to the deeper portion of the space. Diffusion of the administered anesthetic floods the interscalene space, but also extends the solution around the anterior scalene muscle to the phrenic nerve[14] and, as a result, contributes to an undesired side effect of interscalene brachial plexus block (paralysis of the phrenic nerve).[19]

Performance of the supraclavicular technique (Fig 7) in turn requires consideration of whether the nerve branches have or have not been identified. If the nerves have been identified, the needle is advanced to the deeper part of the plexus along its vertical axis, under direct visualization to avoid medial angulation and the risk of pleural puncture. If the nerves have not been identified, half of the anesthetic volume is injected near the posterior region of the subclavian artery, while the other half is administered in its posterosuperior zone below the omohyoid muscle.[20]

Performance of infraclavicular block (Fig 8) requires administration of most of the local anesthetic volume in the posterolateral portion of the axillary artery when the technique involves a proximal infraclavicular approach, while if puncture is performed more distally (below the pectoralis minor muscle), the anesthetic volume should be distributed around the artery. Ootaki et al.[21] obtained excellent clinical results (95% success rate) administering the volume (30 mL) equally on both sides of the axillary artery.

In the case of axillary block (Fig 9) guided by US, the local anesthetic solution should be distributed deep to and superficial to the axillary artery. However, Kapral et al.[20] obtained better results by administering the anesthetic between the axillary artery and vein, a fact that may be explained by the puncture site, very proximal in the arm.

US in Plexus Block: Clinical Trials

With the idea of providing an orientation to the depth of the neural structure to be blocked and to minimize vascular and neural puncture, particularly in patients with external reference points that are difficult to establish,[22,23] interest has developed over the application of ultrasonography in the performance of plexus anesthesia involving brachial[14,20,24,25] and lumbar approaches.[26,27]

The use of US for the easier detection of nervous structures destined for block is not new. In 1978, a Doppler US blood flow detector was used by La Grange et al.[6] to localize the third division of the subclavian artery, rendering the supraclavicular approach to the brachial plexus safer and highly successful. Also, Abramowitz et al.[7] used hand-held Doppler probes to assist in locating the axillary artery for difficult axillary blocks. The authors recommended the use of such probes in cases in which vascular landmarks are used, but not readily found.

Friedl and Fritz[22] presented a technique for accessing the brachial plexus at an axillary level using a linear 7.5-MHz transducer, recommending its application when the brachial artery cannot be well identified by clinical examination and to avoid neurologic deficits due to direct puncture and injection of anesthetic in the nerves. These latter recommendations have yet to be proven.

Normal peripheral nerves of the extremities have

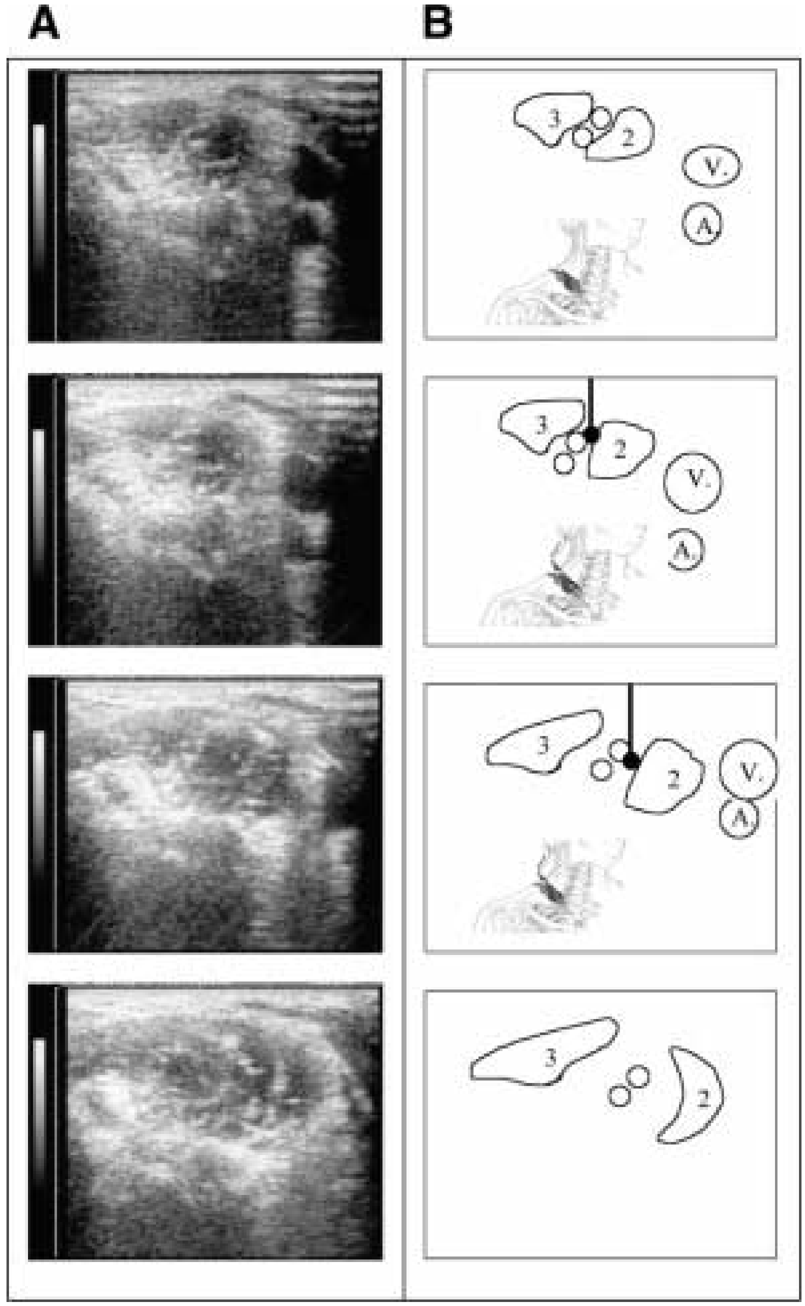

Fig 6. Interscalene brachial plexus block. Transverse cross-section at C6 level, identifying the different muscles and vascular structures in the neck region (A), showing 3 hypodense nodular structures located between the scalene muscles (arrows, B) corresponding to the trunks of the brachial plexus. The upper image corresponds to the anatomical picture prior to puncture. The 2 posterior images show puncture, identifying the needle and progressive dispersion of the anesthetic volume administered into the interscalene space and around the anterior scalene muscle (images after injecting 2 mL and 15 mL of the 1.5% mepivacaine anesthetic solution). The lower image reflects the result after administration of the complete volume of anesthetic solution (40 mL), showing the important anatomical alteration and the difficulties for identifying the different structures. (2) Anterior scalene muscle; (3) middle scalene muscle; (A) carotid artery; and (V) internal jugular vein. Thick dotted line: needle trajectory and tip.

been described as markedly echogenic tubular structures with parallel linear internal echoes on longitudinal sonograms and exhibiting a round to oval cross-section on transverse scans.[28]

Yang et al.,[14] using high-resolution sonographic guidance with a broadband L10 5-MHz probe (HDI 3000; ATL, Bothell, WA), inserted a catheter into the interscalene groove and evaluated location using radiography and computed tomography after the injection of contrast material. The authors described a complex anatomy at the interscalene level, where the brachial plexus appeared as 3 discrete, rounded hypoechoic nodules between the anterior and medial scalene muscles on transverse US in the lower cervical (C6) region, representing the trunks in parasagittal-oblique section. A cluster of hypoechoic nodules corresponding to the divisions were seen cephalad to the subclavian artery on sagittal scans of the supraclavicular region. Successful neural block after 20 minutes and postoperative analgesia were achieved in all patients.

In the most recent investigation, Ootaki et al.,[21] using real-time US guidance for plexus block at the infraclavicular level, concluded that the system can

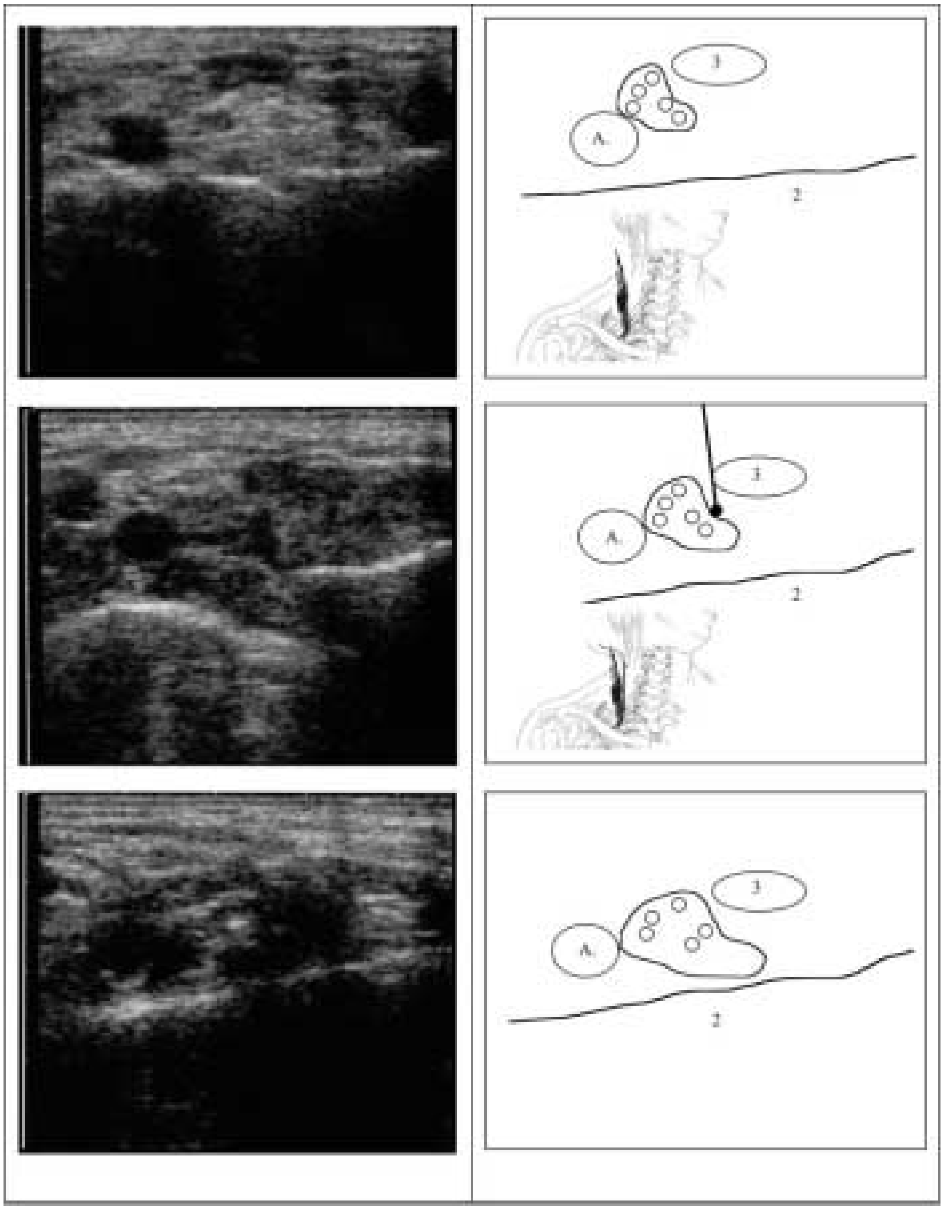

Fig 7. Supraclavicular brachial plexus block. Sagittal cross-section at the level of the first rib. The upper image shows the normal anatomy of the zone. The intermediate image shows the picture following puncture and the administration of 5 mL of local anesthetic solution in the inferior zone of the omohyoid muscle. The lower image corresponds to the situation after injection of the total anesthetic volume (30 mL), showing the important alteration of the anatomical structures. (2) First rib; (3) omohyoid muscle; and (A) subclavian artery. Thick dotted line: needle trajectory and tip.

be used as an alternative to the anatomical landmark-guided technique. Attached to the US probe (7.0 MHz) and for effective needle manipulation, the authors used a needle guide, keeping the needle pass within the US beam (UAGV021A; Toshiba; cost, $1,000). For plexus block, a 23-gauge 60-mm needle was inserted toward the medial aspect of the subclavian artery under real-time US guidance, and the local anesthetic was injected near the subclavian artery 15 mm medial and 15 mm lateral to the latter. Complete sensory block was achieved in 100% of patients for the musculocutaneous and medial antebrachial cutaneous nerves, in 96.7% for the median nerve, and in 95% for the ulnar and radial nerves. Complete motor block was achieved in 100% of patients for the musculocutaneous nerve, in 96.7% for the median nerve, in 90% for the ulnar nerve, and in 93.3% for the radial nerve. No complications were recorded.

Marhoffer et al.[26,27] investigated the benefits of the approach for 3-in-1 block using US in comparison with a nerve stimulator (NS), using 20 mL of 0.5% bupivacaine in both groups. After US or NS-based identification of the femoral nerve, the local anesthetic solution was administered. The onset of sensory block was significantly shorter in the US group compared with NS (US 16 $\pm$ 14 min; NS 27 $\pm$ 16 min; $P < .05$). The quality of sensory block after injection of the local anesthetic was also significantly better in the US group (US 15% $\pm$ 10% of

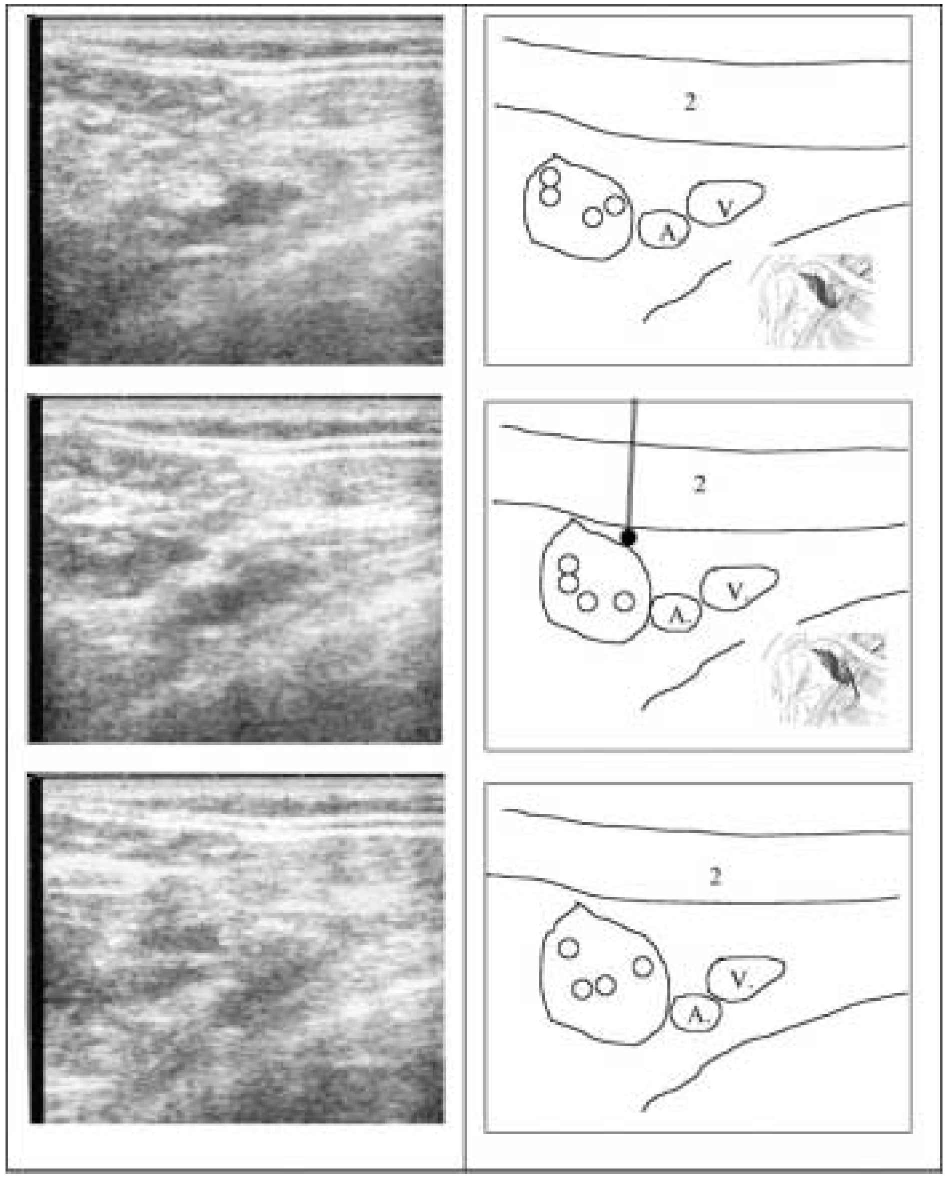

Fig 8. Infraclavicular proximal brachial plexus block. Sagittal cross-section in the infraclavicular zone (below the middle third of the collarbone), showing the normal anatomy in the first image, during puncture (following 10 mL of local anesthetic solution), and after administration of the total volume (40 mL of 1.5% mepivacaine). (2) Pectoralis major muscle; (A) axillary artery; and (V) axillary vein. Thick dotted line: needle trajectory and tip.

initial value; NS 27% ± 14% of initial value; $P < .05$). A good analgesic effect was achieved in 95% of the patients in the US group versus 85% of the patients in the NS group. In the former group, visualization of the cannula tip, the femoral nerve, the major vessels, and local anesthetic spread was possible in 85% of patients. Associated morbidity was recorded only in the NS group in the form of incidental arterial puncture (n = 3). In another related study, it was found that the amount of local anesthetic required for 3-in-1 blocks can be reduced by using US guidance compared with the conventional NS-guided technique.[27] The authors concluded that an US-guided approach for 3-in-1 block reduces the onset time, improves the quality of sensory block, and minimizes the risks associated with this regional anesthetic technique.

Conclusions

We believe ultrasonography for regional anesthesia still requires progressive introduction as a systematic method for producing brachial plexus block, a process hampered by the need for new knowledge and a learning period. Nevertheless, in our opinion, the technique is ideally indicated in certain situations: in patients in which the classical anatomical references are difficult to identify (obese subjects, patients in whom the pulse cannot be localized, etc.), during the learning phase of plexus anesthesia, or when performing unusual techniques. In this context, the application of imaging technology can allow us to increasingly identify structures in proximity to the plexus, which can be used as references.

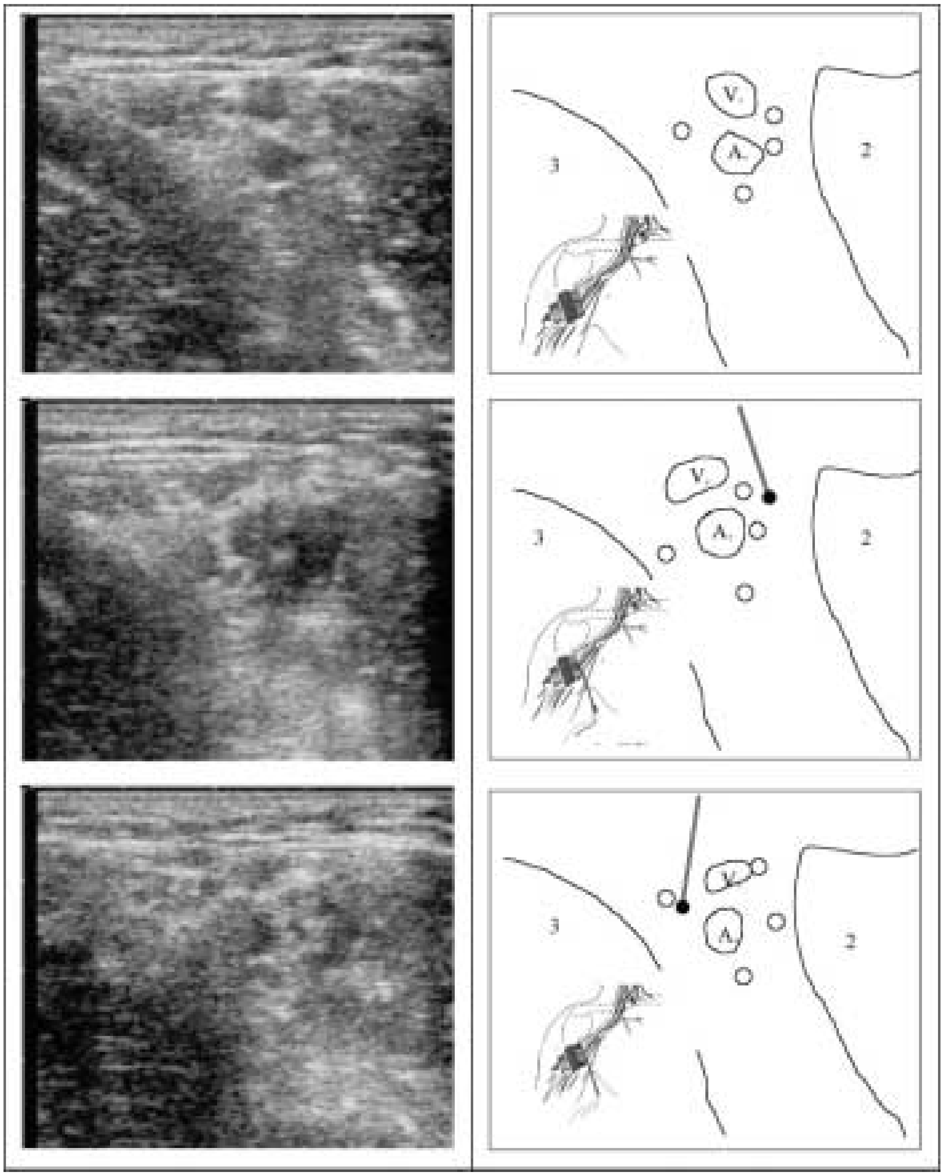

Fig 9. Axillary technique of brachial plexus block. Transverse cross-section of the upper third of the arm. The upper image shows the normal anatomy, while the lower images correspond to the situation after administering 20 mL of 1.5% mepivacaine on both sides of the axillary artery. (2) Coracobrachial and biceps muscles; (3) triceps muscle of the arm; (A) humeral artery; (V) humeral vein. Thick dotted line: needle trajectory and tip.

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