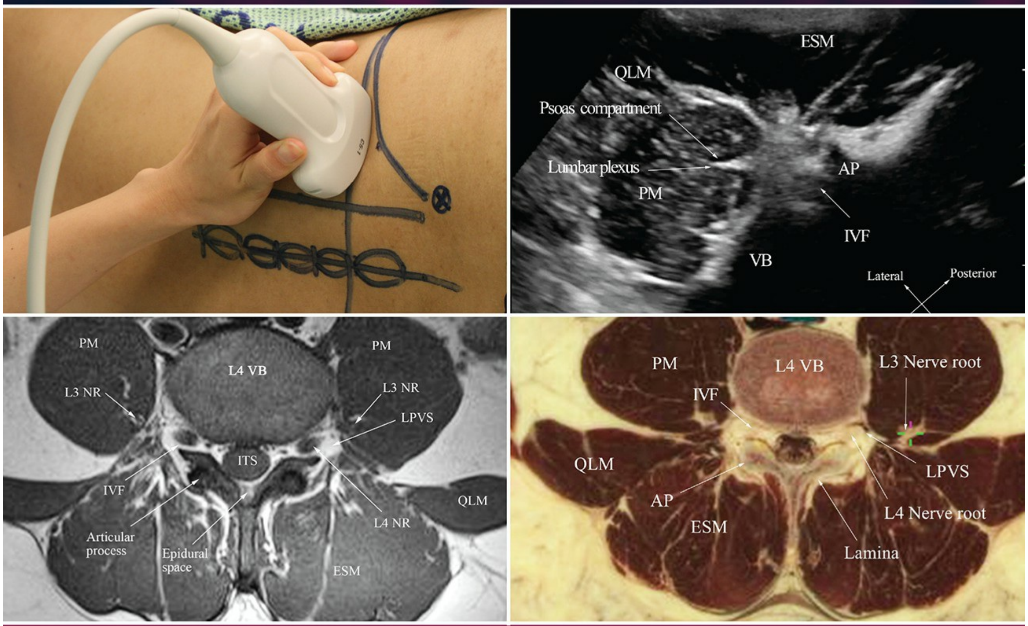
ATLAS OF SONOANATOMY for Regional Anesthesia and Pain Medicine



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NOTICE

ATLAS OF
Sonoanatomy for Regional Anesthesia and Pain Medicine

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PREFACE

This Atlas is intended to illustrate the aspects of sonoanatomy that are important in the performance of ultrasound guided nerve blocks for acute and chronic pain medicine. The use of ultrasound has increased exponentially in the area of regional anesthesia and pain medicine in the last decade. During this time of evolution, learning sonoanatomy was hampered with the need to refer to various resources for the technical aspects of machine optimization, correlating sonoanatomy with gross anatomy and other imaging modalities and discovering the ergonomic aspects of imaging and intervention.

For regional anesthesia, transitioning from landmark based techniques for nerve blocks to real time ultrasound image guided nerve blocks required the development of the ability to visualize and understand the cross sectional anatomy of the area of interest outside the traditional transverse, sagittal and coronal axis views presented by current modalities such as computed tomography and magnetic resonance imaging.

For pain medicine, transitioning from fluoroscopy guided interventions to real time ultrasound image guided or assisted interventions required the development of new points of reference for interventions and a move away from traditional fluoroscopic guided endpoints for intervention.

This book is divided into chapters that present the sonoanatomy specific for interventions in the area of interest. With a total of 768 illustrations this book is designed to be the complete resource for gross anatomy, CT, MR and sonoanatomy of the specific area of interest for easy cross-reference between gross anatomy and the various modalities allowing users to better understand the sonoanatomy. These cross-referenced images are presented with the relevant anatomy in the same cross sectional plane of the ultrasound image. Within each area of interest, users are guided to acquire the ideal ultrasound image for targeted intervention with attention to the required ergonomics for operator safety and comfort.

Each approach to the relevant sonoanatomy is accompanied by clinical pearls to aid readers acquire ultrasound images of the area of interest with ease, provide guidance for successful intervention and avoid pitfalls.

This Atlas has been written both as an introduction for new users to ultrasonography and as a review and instruction aid for users familiar with the subject. It is our sincere hope that the users of this book will develop an appreciation of the ease and usefulness of ultrasonography and the beauty of sonoanatomy.

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The anatomic images are courtesy of the Visible Human Server at Ecole Polytechnique Fédérale de Lausanne, Visible Human Visualization Software (http://visiblehuman.epfl.ch), and Gold Standard Multimedia www.gsm.org. All figures and illustrations in this book are reproduced with the kind permission from www.aic.cuhk.edu.hk/usgraweb of the Department of Anesthesia and Intensive care of The Chinese University of Hong Kong.

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CHAPTER 1

Basics of Musculoskeletal and Doppler Ultrasound Imaging for Regional Anesthesia and Pain Medicine

A sound knowledge of the basic concepts of musculoskeletal ultrasound is essential to obtain optimal images during ultrasound-guided regional anesthesia (USGRA). This chapter briefly summarizes the ultrasound principles that the operator should be aware of when performing USGRA.

Ultrasound Transducer Frequency

Spatial resolution is the ability to distinguish two closely situated objects as separate. Spatial resolution includes axial resolution (the ability to distinguish two objects at different depths along the path of the ultrasound beam) and lateral resolution (the ability to distinguish two objects that are side by side perpendicular to the ultrasound beam). Higher transducer frequencies increase spatial resolution but penetrate poorly into the tissues. Lower transducer frequencies penetrate deeper into the tissues at the expense of lower spatial resolution. Spatial resolution and beam penetration have to be balanced when choosing the transducer frequency.

Examples: A high-frequency (6–13 MHz) ultrasound transducer is used to image superficial structures such as the brachial plexus in the interscalene groove or supraclavicular fossa. A lower-frequency transducer (5–10 MHz) is suitable for slightly deeper structures such as the brachial plexus in the infraclavicular fossa, and a low-frequency transducer (2–5 MHz) is used to image deep structures such as the lumbar paravertebral region or the sciatic nerve. High-frequency (6–13 MHz) linear transducers with a small footprint (25–26 mm) are particularly suited for regional blocks in young children.

Scanning Plane

Scans can be performed in the transverse (axial) or longitudinal plane. During a transverse scan, the transducer is oriented at right angles to the long axis of the target, producing a cross-sectional display of the structures (Fig. 1-1A). During a longitudinal (sagittal) scan, the transducer is oriented parallel to the long axis of the target (eg, a blood vessel or nerve) (Fig. 1-1B). During USGRA, ultrasound scans are most commonly performed in the transverse plane in order to easily visualize the nerves, the adjacent structures, and the circumferential spread of the local anesthetic.

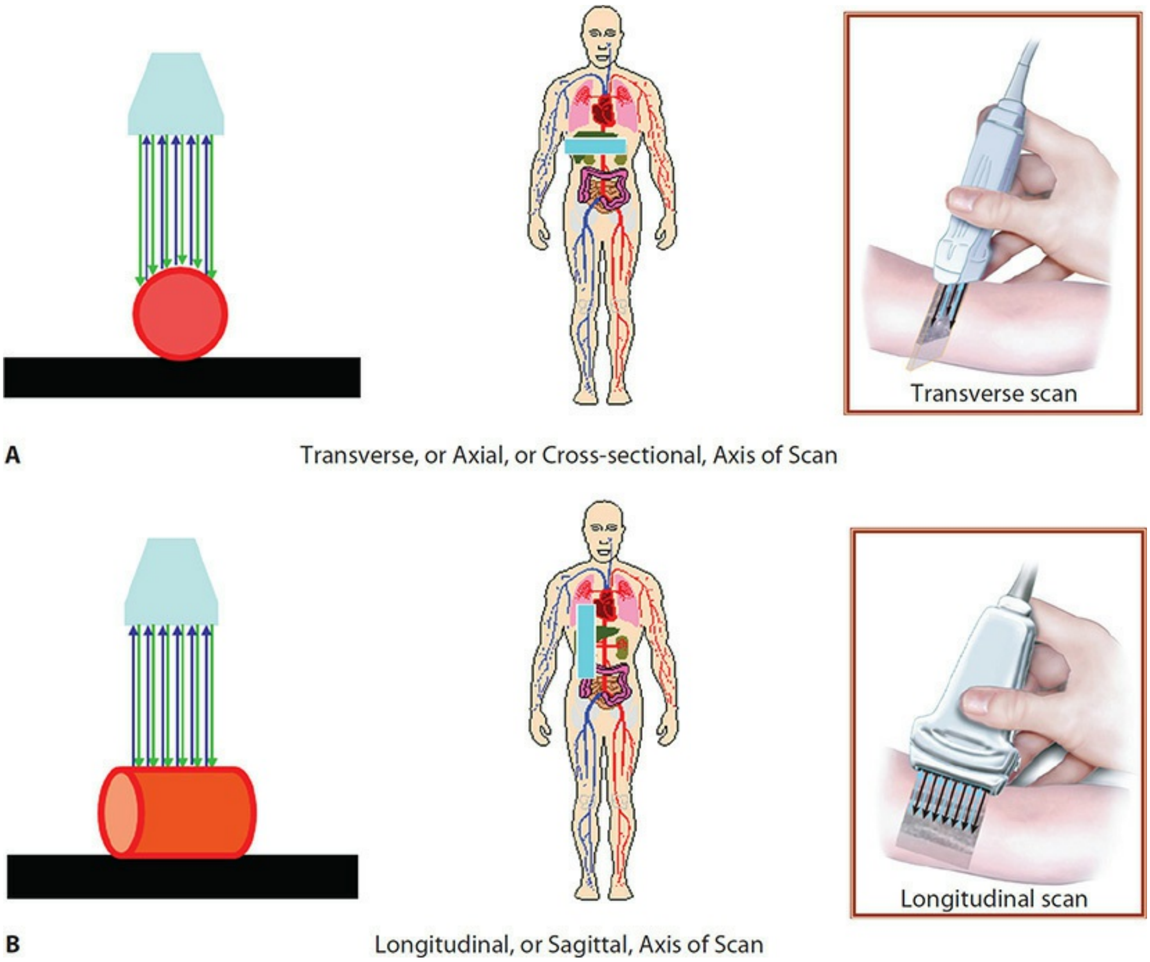

FIGURE 1-1 ■ Axis of scan.

Transducer and Image Orientation

The ultrasound image must be correctly oriented in order to accurately identify the anatomical relationships of the various structures on the display monitor. Ultrasound transducers have an orientation marker (eg, a groove or a ridge) on one side of the transducer, which corresponds to a marker on the monitor (eg, a dot or logo) (Fig. 1-2). There are no accepted standards on how to orient a transducer, but it is common to have the orientation marker on the transducer directed cephalad when performing a longitudinal scan, and directed towards the right side of the patient when performing a transverse scan (Fig. 1-3). In this way, the monitor “marker” should be at the upper-left corner of the screen representing the cephalad end during a longitudinal scan, or the right side of the patient during a transverse scan (Fig. 1-3). The top of the monitor represents superficial structures, and the bottom of the monitor deep structures.

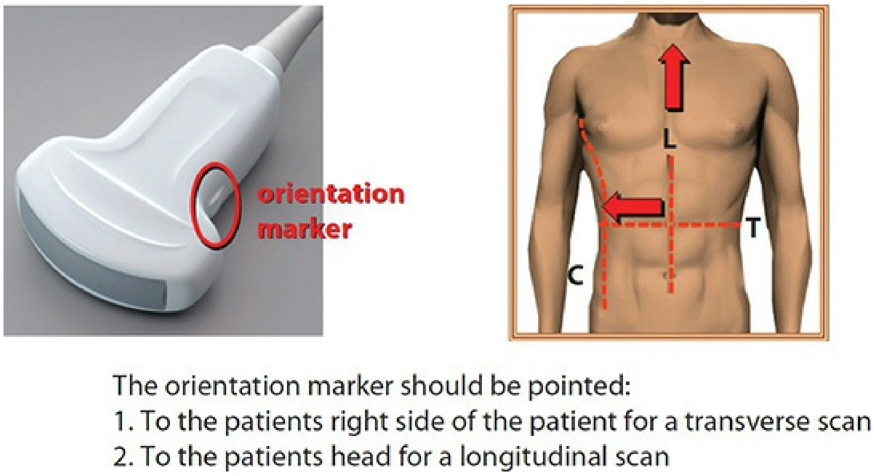

FIGURE 1-2 ■ Transducer orientation. Note the orientation marker varies between different providers of ultrasound systems. L, longitudinal, T, transverse and C, coronal.

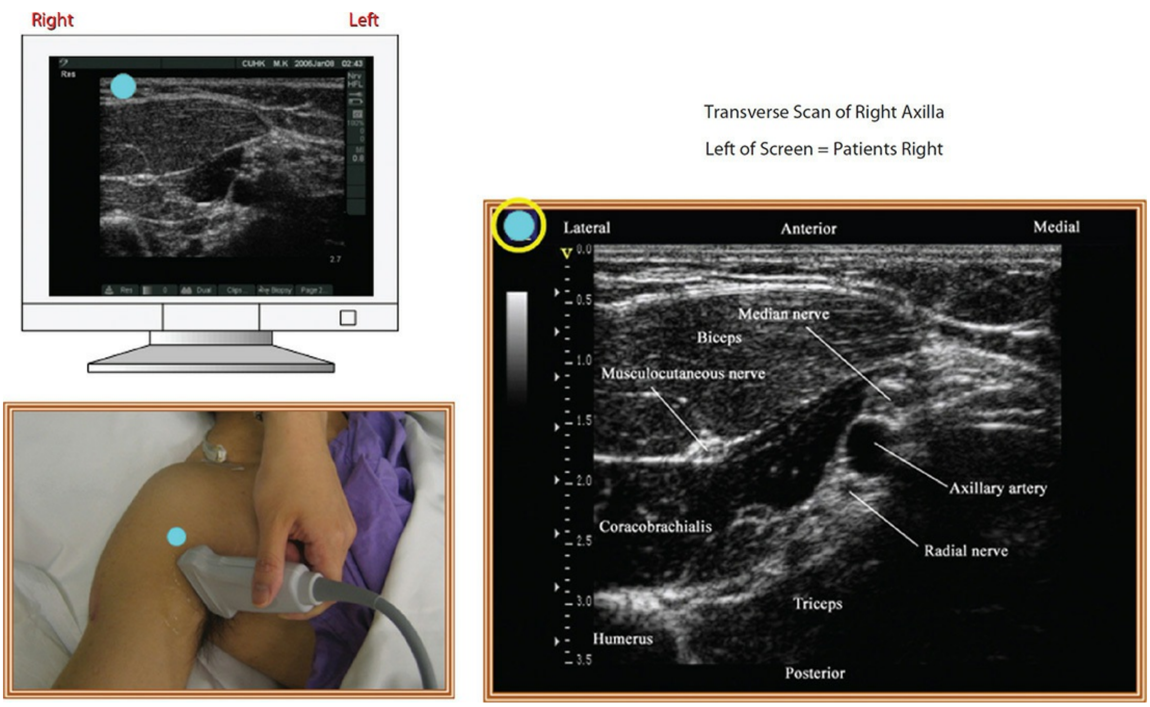

FIGURE 1-3 ■ Image orientation – transverse scan.

Image Optimization

The image should be optimized by adjusting the depth, focal zone, and gain. Imaging depth affects temporal resolution (the ability to accurately depict moving structures) and should be reduced to the smallest field of view (FOV) that is practical. The focal zone should be positioned at the region of interest to increase lateral resolution at that site. Reducing the total number of focal zones also improves temporal resolution. Finally, the time gain compensation (TGC) and overall gain should be adjusted to produce an image with appropriate brightness. The TGC is usually adjusted with the near field gain turned down and the far field gain turned up in steady progression to adjust for beam attenuation with depth.

Echogenicity

Certain terms are frequently used to describe the sonographic appearance of musculoskeletal structures (Fig. 1-4):

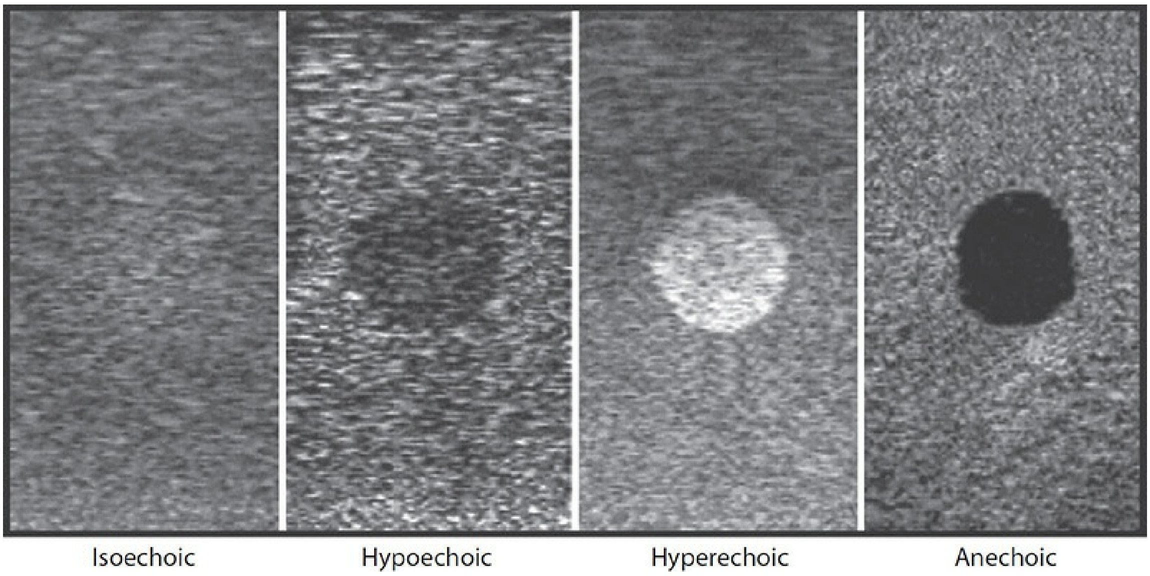

FIGURE 1-4 ■ Echogenicity of tissues.

Isoechoic: The structure is of the same brightness or echogenicity as the surrounding tissues.
Hyperechoic: The structure is bright.
Hypoechoic: The structure is dark but not completely black.
Anechoic: The structure has no echoes and appears completely black.

Contrast resolution is the ability to distinguish subtle differences in echogenicity between two adjacent structures.

Axis of Intervention

During USGRA, the block needle can be visualized in its short axis (out-of-plane approach) (Fig. 1-5) or long axis (in-plane approach) (Fig. 1-6). In the out-of-plane approach, the needle is initially outside the plane of imaging and therefore not visible. The needle only becomes visible when it crosses the plane of imaging and is seen as an echogenic dot on the monitor (Fig. 1-5). It is important to note that this echogenic dot may not represent the tip of the needle because it is a short-axis view. In the in-plane approach the needle is inserted along the plane of imaging and therefore both the shaft and tip of the needle are visible on the monitor (Fig. 1-6).

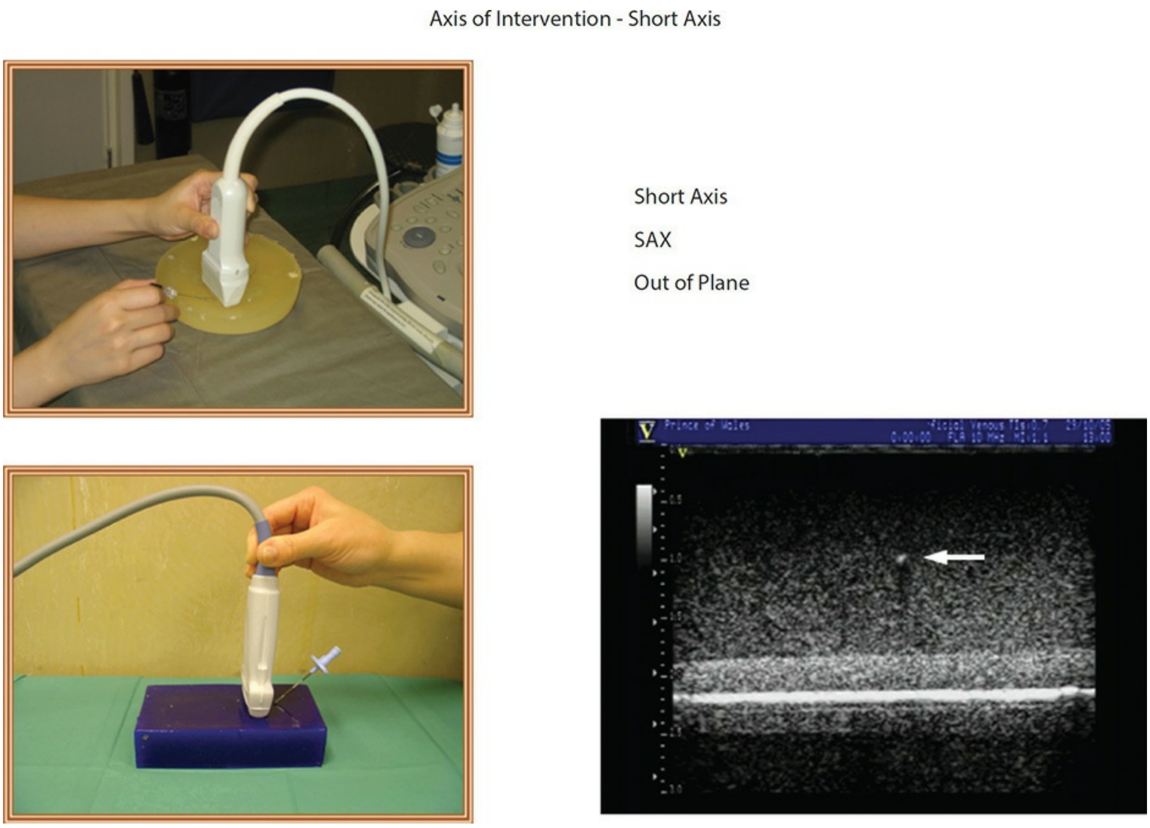

FIGURE 1-5 ■ Axis of intervention – out-of-plane needle insertion.

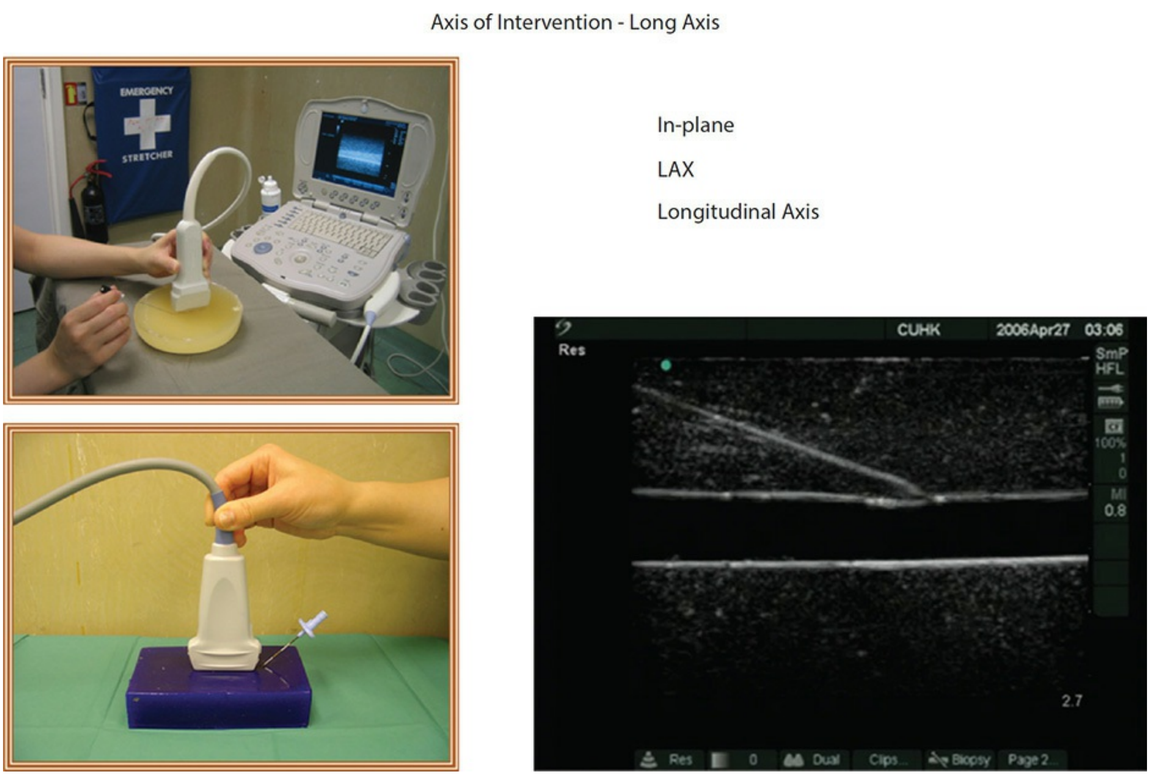

FIGURE 1-6 ■ Axis of intervention – in-plane needle insertion.

Both approaches are commonly used, and there are no data showing that one is better than the other. Pros and cons for both methods have been debated. Proponents of the out-of-plane approach have had great success with this method and claim that it causes less needle-related trauma and pain because the needle is advanced through a shorter distance to the target. However, critics of the out-of-plane approach express concerns that the inability to reliably visualize the needle and using tissue movement as a surrogate marker to locate the needle tip during a procedure can lead to complications. The needle is better visualized in the in-plane approach, but this requires good hand–eye coordination, and reverberation artifacts from the shaft of the needle can be problematic. Moreover, there are claims that the in-plane approach also causes more discomfort in awake patients because longer needle insertion paths are required.

Field of View and Needle Visibility

Having an adequate FOV during USGRA is important because it not only allows one to visualize the "target," but also the neighboring structures (eg, blood vessel, pleura, etc.) that one wishes to avoid injury to. Linear array transducers have a narrow FOV, whereas curved array transducers have a divergent ultrasound beam resulting in a wider FOV (Fig. 1-7).

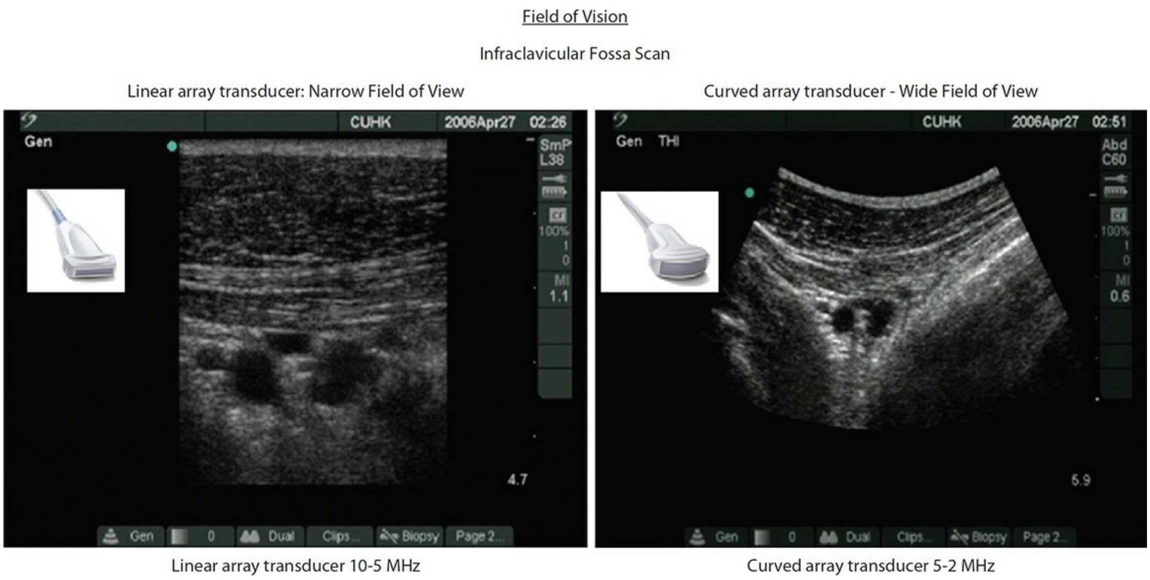

FIGURE 1-7 ■ Comparative field of view of the infraclavicular fossa with linear and curved array transducers.

Needles are best visualized when imaged perpendicular to the ultrasound beam. Needles at steep angles required for deep blocks may not be easily visualized with linear array transducers. Linear array transducers are best suited for superficial blocks (eg, axillary or interscalene brachial plexus block, femoral nerve block). Curved array transducers are more suitable for deep blocks (eg, sciatic nerve block, lumbar plexus block, and central neuraxial blocks). However, curved array transducers have reduced lateral resolution at depth due to the diverging ultrasound beam.

Other factors can also influence needle visibility. The needle is better visualized in its long axis than in its short axis, and its visibility decreases linearly with smaller needle diameters. The needle tip is better visualized when in its long axis for shallow angles of insertion (less than 30 degrees), and in its short axis when the angle of insertion is steep (greater than 60 degrees). This is also true when the needle is inserted with its bevel facing the ultrasound transducer. To overcome the effect of angle on needle visibility, some high-end ultrasound machines allow the operator to steer the ultrasound beam (beam steering) towards the needle during steep insertions. However, this requires experience, and decreases in needle visibility can still occur. Needle visibility is also enhanced in the presence of a medium-sized guide wire. Priming a needle with saline or air, insulating it, or inserting a stylet prior to insertion does not improve visibility.

We believe that the anesthesiologist's skill in aligning the needle along the plane of imaging is by far the most important variable influencing needle visibility because minor deviations of even a few millimeters from this plane can result in an inability to visualize the needle. Even with experience, needle tip visibility is a problem when performing blocks at depth, in areas that are rich in fatty tissue, and in the elderly. Under such circumstances gently jiggling (rapid in-and-out movement) the needle and observing tissue movement or performing a test injection of saline or 5% dextrose (1–2 mL) and observing tissue distention can help locate the position of the needle tip. The preference is for 5% dextrose for the latter when nerve stimulation is used because it does not increase the electric current required to elicit a motor response.

Anisotropy

Anisotropy, or angular dependence, is a term used to describe the change in echogenicity of a structure with a change in the angle of insonation of the incident ultrasound beam (Fig. 1-8). It is frequently observed during scanning of nerves, muscles, and tendons. This occurs because the amplitude of the echoes returning to the transducer varies with the angle of insonation. Nerves are best visualized when the incident beam is at right angles; small changes in the angle away from the perpendicular can significantly reduce their echogenicity. Therefore, during USGRA the transducer should be tilted from side to side to minimize anisotropy and optimize visualization of the nerve. Although poorly understood, different nerves also exhibit differences in anisotropy; this may be related to the internal architecture of the nerve.

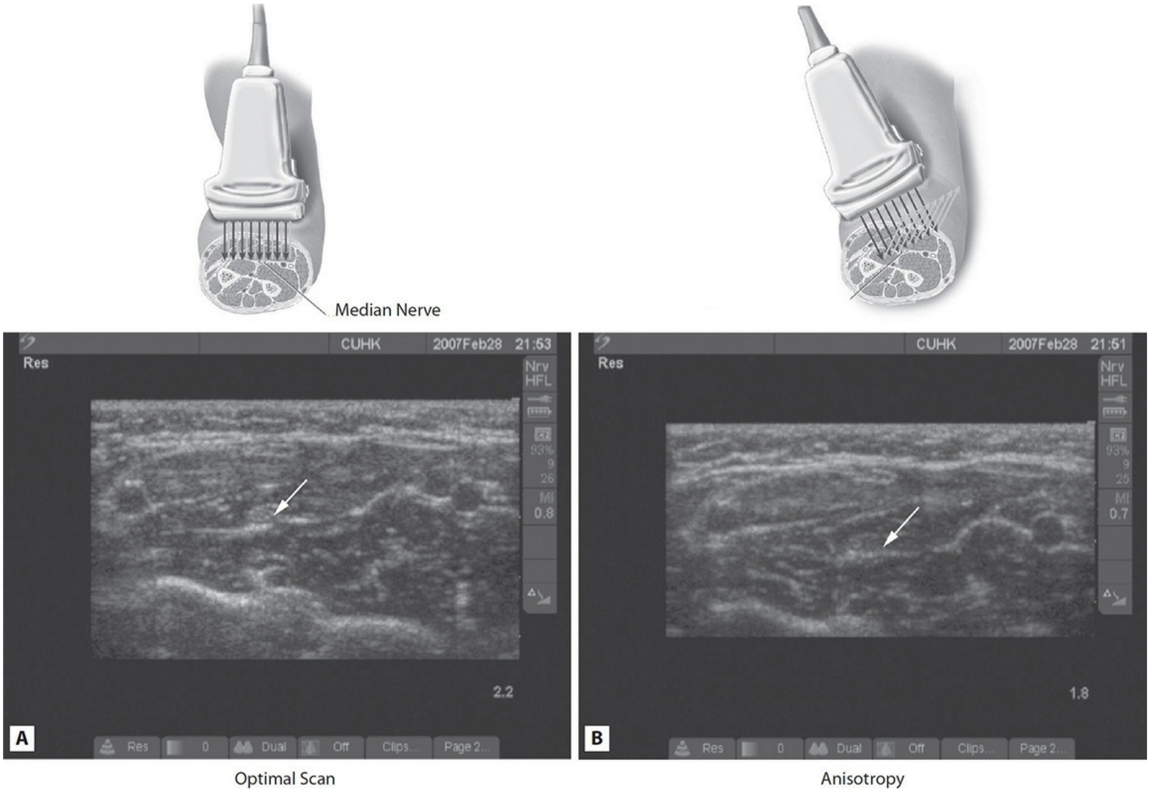

FIGURE 1-8 Anisotropy – effect of angulation of the transducer on the echogenicity of the median nerve (white arrow) in the forearm. The median nerve appears hypoechoic in the image on the right.

Identification of Normal Structures

Nerve

Peripheral nerves consist of hypoechoic nerve fascicles surrounded by hyperechoic connective tissue and have a "honeycomb" appearance in the transverse axis (Fig. 1-9). They have a fibrillar appearance in the longitudinal axis with fine parallel hyperechoic lines separated by fine hypoechoic lines. Generally, nerves appear hyperechoic, but the appearance can vary depending on the surrounding structures. For example, nerves appear hyperechoic when surrounded by hypoechoic muscle, but can appear hypoechoic when surrounded by hyperechoic fat. The echogenicity of a nerve may also vary depending on the location where it is scanned; for example, the brachial plexus nerves appear hypoechoic at the interscalene groove, but are hyperechoic at the infraclavicular fossa and axilla. The exact reason for this is not clear, but may be related to the relative proportion of neural and connective tissue within the nerve. The ratio of neural to non-neural tissue content within the epineurium of the nerve increases from 1:1 in the interscalene/supraclavicular fossa to 1:2 in the mid-infraclavicular/paracoracoid regions. Nerve motion can also be demonstrated on dynamic ultrasound imaging.

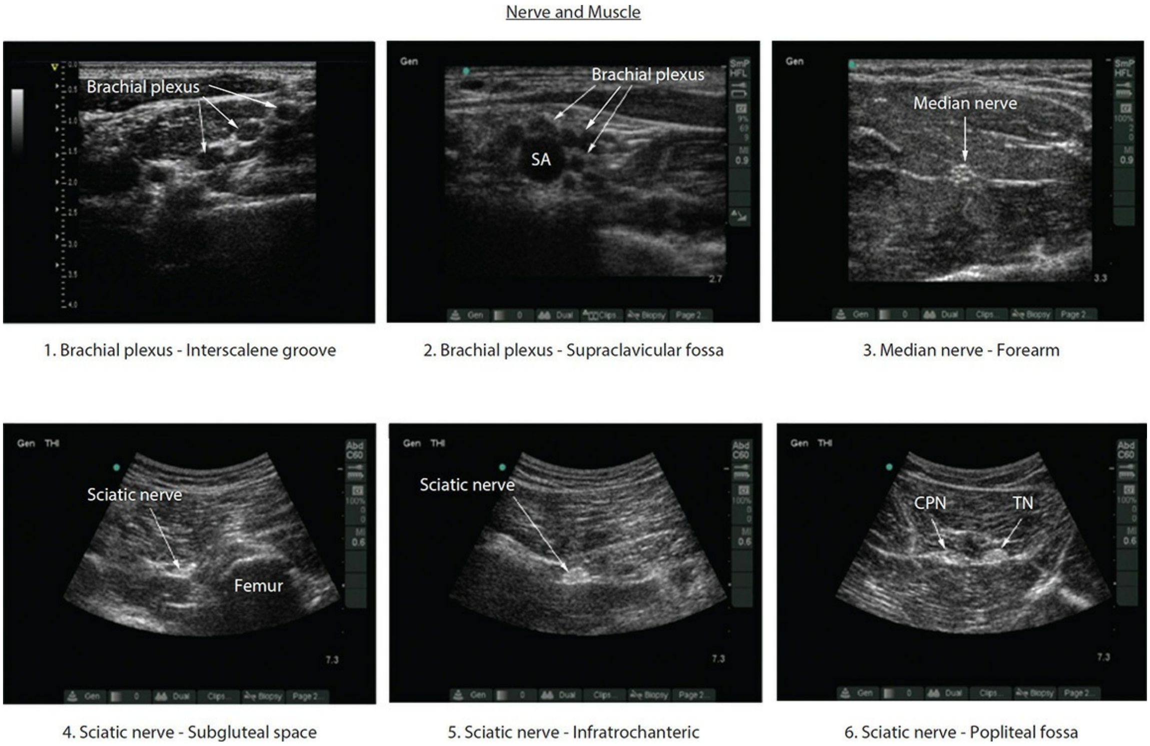

FIGURE 1-9 ■ Echogenicity of muscles and nerves at different locations in the upper and lower extremity. SA, subclavian artery, CPN, common peroneal nerve, TN, tibial nerve.

Tendon

Tendons are hyperechoic with a fibrillar pattern on longitudinal scans. Tendons are more hyperechoic than nerves and move more than adjacent nerves when the corresponding muscle is contracted or passively stretched.

Muscle

Muscle fiber bundles are hypoechoic. The separating and surrounding connective tissue perimysium and epimysium are hyperechoic (Fig. 1-9). Muscle fibers converge to become tendons or aponeuroses.

Subcutaneous Fat

Subcutaneous fat lobules appear as round to oval hypoechoic nodules that are separated by fine hyperechoic septa. They are slightly compressible and appear similar on transverse and longitudinal scans.

Bone

Bone reflects most of the ultrasound beam. Therefore, the bone surface appears hyperechoic on ultrasound with posterior acoustic shadowing, and possibly posterior reverberation, distal to it (Fig. 1-10).

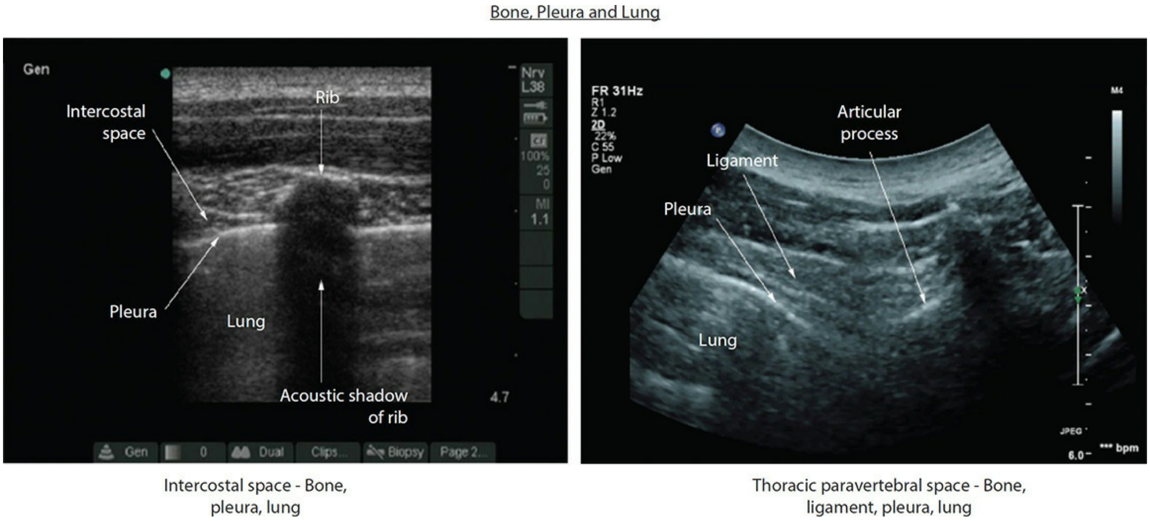

FIGURE 1-10 ■ Echogenicity of bone, pleura and lung at the intercostal space. Note the acoustic shadow deep to the rib.

Fascia

Fascia, peritoneum, and aponeuroses appear as thin hyperechoic layers.

Blood Vessel

Blood vessels have anechoic lumens. Arteries are intrinsically pulsatile and are not compressible with moderate pressure. Veins are not pulsatile and are compressible. Color Doppler or Power Doppler modes can also be used to demonstrate the presence of blood flow and differentiate arteries from veins.

Pleura

The pleura appear as a hyperechoic line slightly deep to the hyperechoic ribs (Fig. 1-10). "Comet-tail" artifacts may be present as vertically oriented echogenicities arising from the pleura. On real-time imaging, sliding movement between the parietal and visceral pleura can be discerned with respiration (lung sliding sign).

Special Ultrasound Features

Tissue Harmonic Imaging

Harmonics refer to frequencies that are integral multiples of the frequency of the transmitted pulse (the fundamental frequency or first harmonic). The second harmonic has a frequency of twice the fundamental frequency. Harmonics are generated due to tissues distorting the transmitted pulse, usually at the center of the image (midfield) rather than at superficial or deep locations. Structures that cause imaging artifacts also tend to produce less or no harmonics. Tissue Harmonic Imaging (THI) is a technique in which structures that produce harmonics are selectively displayed, reducing imaging artifacts. This results in reduced noise and improved spatial and contrast resolution (Fig. 1-11). THI is most suitable for assessment of midfield structures.

Tissue Harmonic Imaging

Sagittal Scan - Infraclavicular Fossa

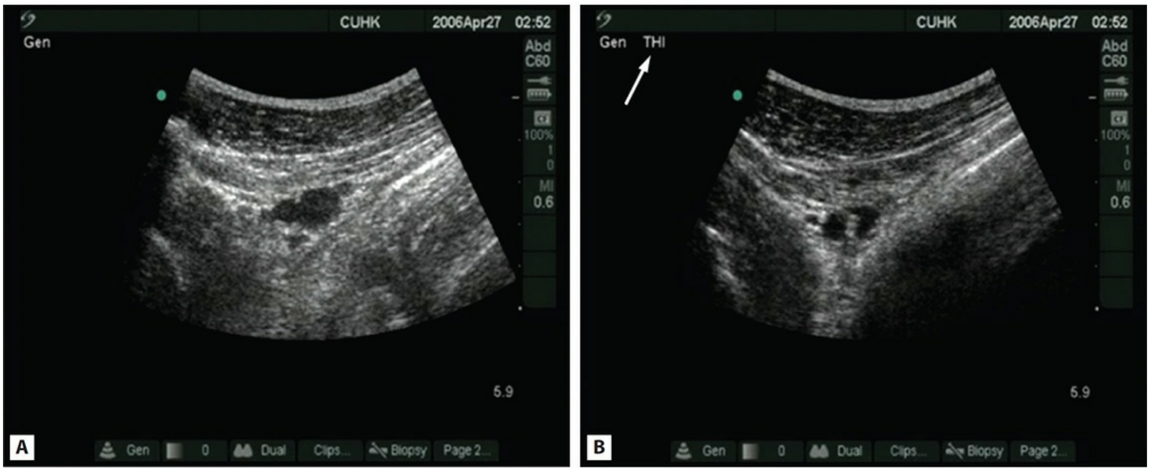

FIGURE 1-11 ■ Effect of Tissue Harmonic Imaging (THI) during ultrasound imaging of the infraclavicular fossa. Note the improved spatial and contrast resolution on the right.

Compound Imaging

Ultrasound images depend on reflection of the ultrasound beam from tissue interfaces back to the transducer. Not all tissues are good reflectors, and certain structures cause scattering of the ultrasound beam resulting in scattered signals radiating in all directions. As a result only a small amount of energy is reflected back to the transducer. The scattering of the ultrasound beam results in noise, which makes the ultrasound image appear grainy. In compound imaging, the same structure is imaged from several different angles using computed beam steering. The returning echoes are then processed producing a composite image that has reduced noise and improved definition (Fig. 1-12). The disadvantage of compound imaging is increased blurring of the image with movement.

Compound Imaging

Transverse Scan of the Axilla

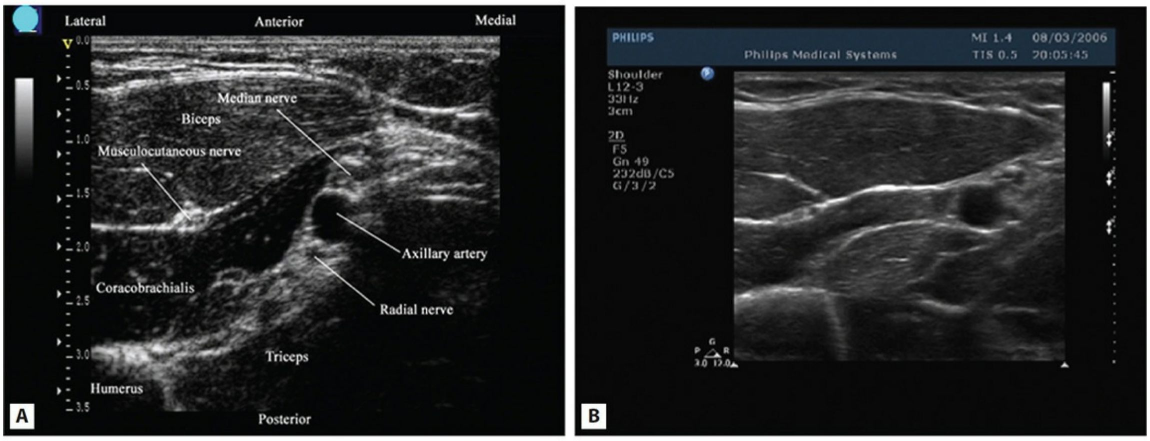

FIGURE 1-12 ■ Effect of Compound Imaging during ultrasound imaging of the axilla. Note the reduction in noise and the improved definition of the image on the right.

Panoramic Imaging

Conventional 2-D ultrasound has a limited FOV and allows visualization of only a small portion of any large structure. Panoramic imaging, as the name implies, is a technique used to extend the FOV so that larger structures can be visualized in their entirety. During a panoramic scan, the operator slowly slides the transducer across a region of interest. Image information obtained during this motion is accumulated and then combined to form the composite panoramic image (Fig. 1-13). Although useful for annotation, documentation, teaching, and research, it is rarely used during USGRA at present.

Panoramic Imaging of the Forearm

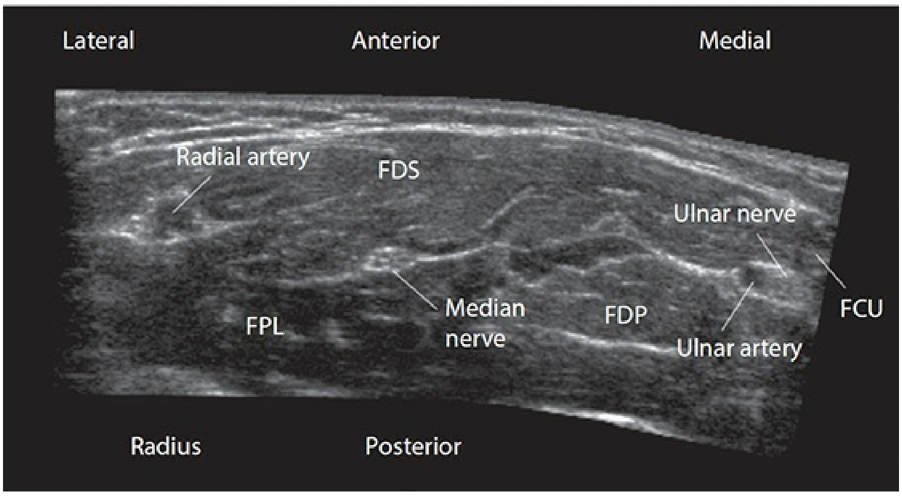

FIGURE 1-13 Panoramic transverse sonogram of the midforearm. FDS, flexor digitorum superficialis; FDP, flexor digitorum profundus; FPL, flexor pollicis longus; FCU, flexor carpi ulnaris.

Three-Dimensional Ultrasound

Three-dimensional ultrasound acquires data as a volume and allows reconstruction at any imaging plane without needing to move the transducer (Figs. 1-14 and 1-15). This can improve spatial awareness at the region of interest, visualization of the block needle, and distribution of the local anesthetic. Potential advantages include reduced needle-associated complications and increased block success with smaller volumes of local anesthetic. In addition, the volume data can be stored and retrospectively analyzed for teaching or research. The main challenges with 3-D ultrasound at present include lack of availability of ergonomic probes that can operate at high frequencies to assess superficial structures, slow screen refresh rates, and reduced temporal resolution when performing real-time interventions.

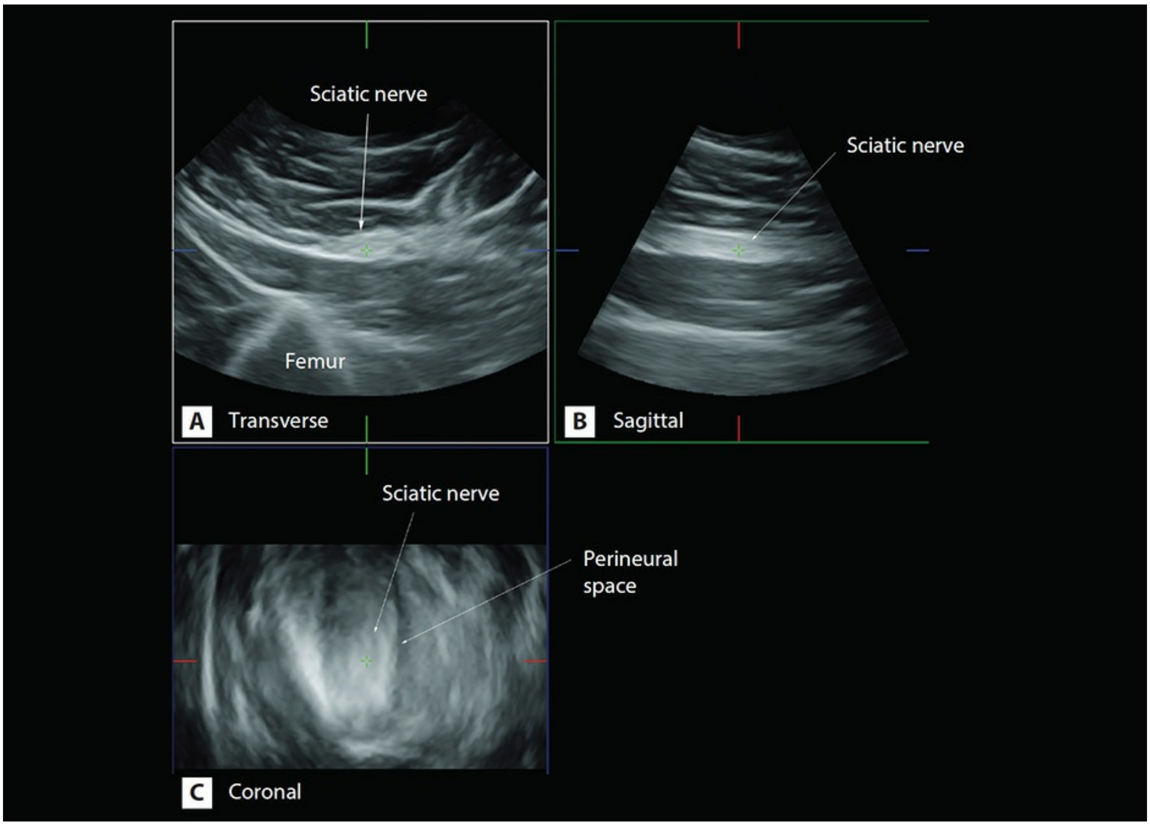

FIGURE 1-14 ■ A multiplanar 3-D ultrasound image of the sciatic nerve at the midthigh with the reference marker (green crosshair) placed over the sciatic nerve.

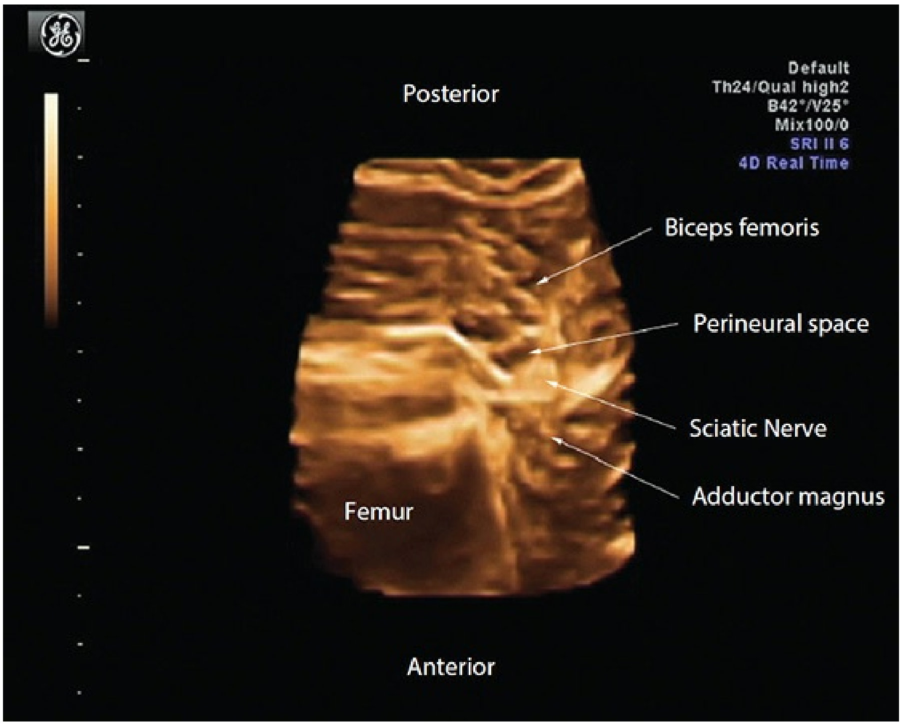

FIGURE 1-15 ■ A rendered 3-D ultrasound image of the sciatic nerve at the midthigh. The front and right surfaces of the 3-D volume are displayed. Note the hypoechoic perineural space posterior to the sciatic nerve in this image.

Artifacts

An ultrasound artifact is information that is visible in the ultrasound image that does not correlate with any anatomical structure. The ultrasound machine makes several assumptions when generating an image:

1. The ultrasound beam travels in a straight line with a constant rate of attenuation.
2. The speed of sound through body tissue is 1540 meters/second.
3. The ultrasound beam is infinitely thin with all echoes originating from its central axis.
4. The depth of a reflector is directly related to the round-trip time of the ultrasound signal.

Artifacts arise when there is deviation from these assumptions. Some artifacts are undesirable and interfere with interpretation, whereas others help identify certain structures. It is essential to recognize them in order to avoid misinterpretation. Therefore, whenever a structure appears abnormal on ultrasound, it must be examined at different angles and orientations to avoid making a wrong interpretation. Real anatomical structures are visible in all planes of imaging, whereas artifacts are generally only visible in one plane.

Artifacts that are frequently encountered during USGRA include:

1. **Contact artifact**

   This is the most common artifact that occurs whenever there is a loss of acoustic coupling between the skin and the transducer. This could simply occur because the transducer is not touching the skin, but more frequently it is due to air bubbles that are trapped between the skin and the transducer. Therefore, it is prudent to apply liberal amounts of ultrasound gel to exclude air from the skin–transducer interface.

2. **Reverberation artifact**

   Reverberation artifacts, also known as “repetitive echoes,” occur whenever there is repeated reflection of the ultrasound beam between two highly reflective surfaces. Some of the ultrasound signals returning to the transducer are reflected back, which then strike the original interface and are reflected back towards the transducer a second time. As a result the first reverberation artifact is twice as far from the skin surface as the original interface. One may also see a second or third reverberation artifact (Fig. 1-16). Due to attenuation, the intensity of the artifacts decreases with increasing distance from the transducer. Reverberation artifacts are frequently seen during ultrasound-guided axillary brachial plexus blocks, particularly when the needle is viewed in its long axis (Fig. 1-17). They are reduced if the needle is less perpendicular to the transducer, but this may also reduce needle visibility.

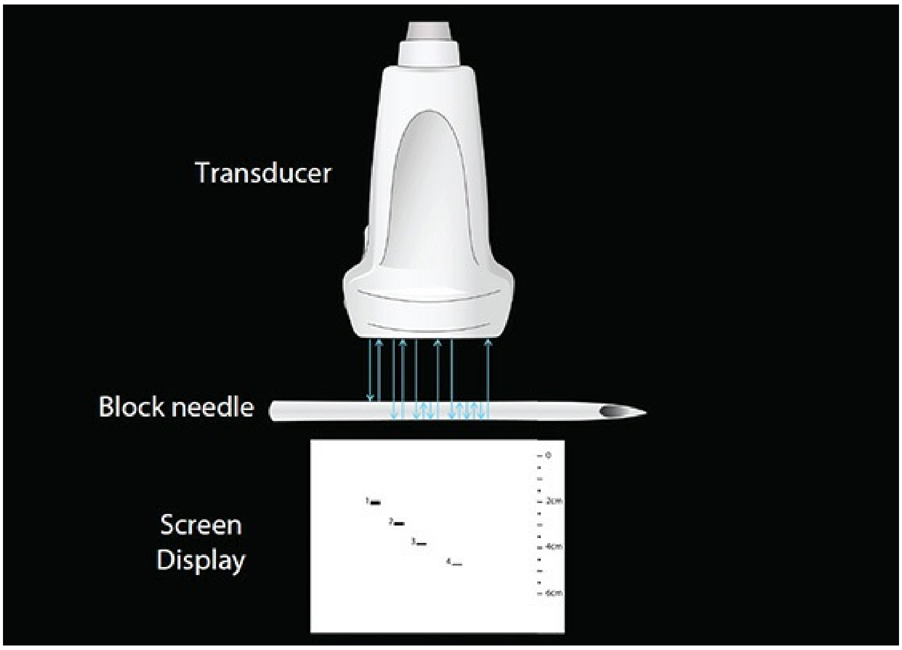

FIGURE 1-16 ■ Schematic diagram illustrating how a reverberation artifact is produced.

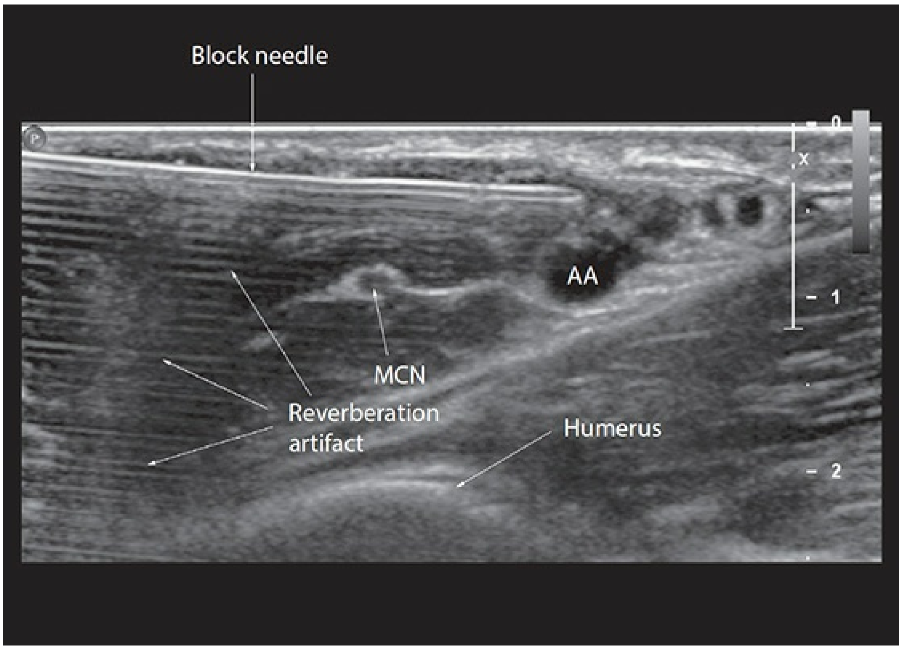

FIGURE 1-17 ■ Reverberation artifact induced by the block needle during an ultrasound-guided axillary brachial plexus block. AA, axillary artery; MCN, musculocutaneous nerve.

3. **Mirror image artifact**

Mirror image artifact is a type of reverberation artifact that occurs at highly reflective interfaces. The first image is displayed in the correct position, and a false image is produced on the other side of the reflector due to its mirrorlike effect (Fig. 1-18).

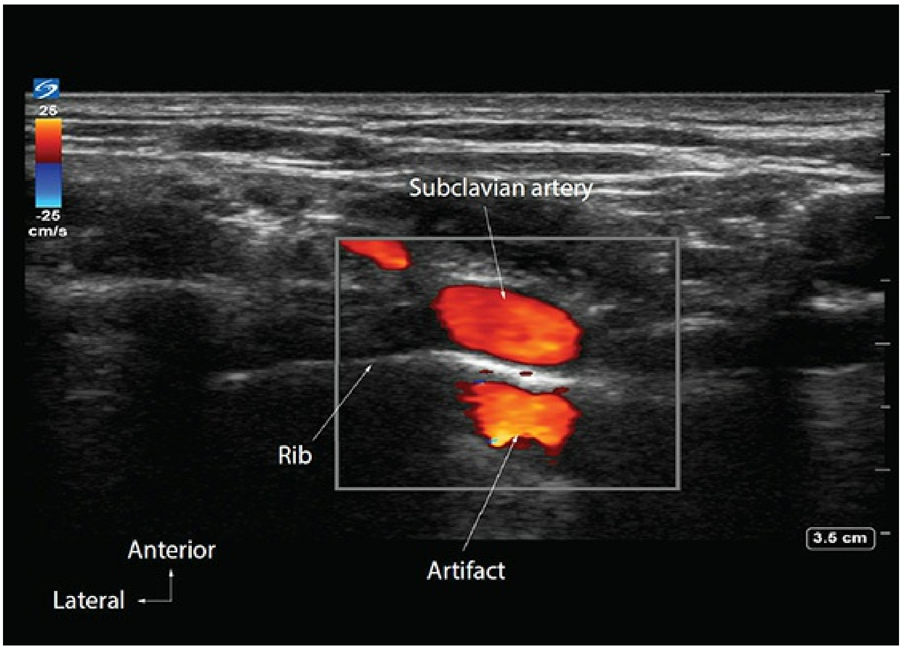

FIGURE 1-18 ■ Mirror image artifact of the subclavian artery.

4. **Propagation speed artifact**

These artifacts occur when the media through which the ultrasound beam passes does not propagate at 1540 meters/second, resulting in echoes that appear at incorrect depths on the monitor. An example of propagation speed artifact is the "bayonet artifact," which has been reported during an ultrasound-guided axillary brachial plexus block. The shaft of the needle appeared bent when it accidentally traversed the axillary artery. We have observed the same phenomenon after local anesthetic injection during a popliteal sciatic nerve block (Fig. 1-19). This happens because of the difference in the velocity of sound between whole blood (1580 meters/second), or the injected local anesthetic, and soft tissue (1540 meters/second).

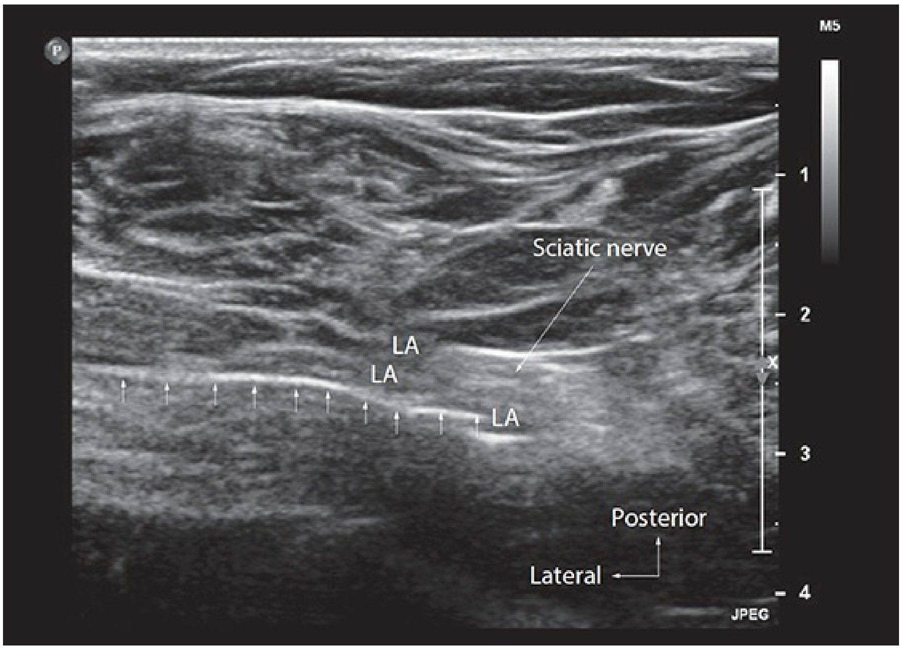

FIGURE 1-19 Bayonet artifact induced by the local anesthetic injection during an ultrasound guided popliteal sciatic nerve block. Note the shaft of the needle appears bent close to the area occupied by the local anesthetic.

5. **Acoustic shadowing**

   An acoustic shadow is a hypoechoic or anechoic region deep to surfaces that are highly reflective or attenuating such as bone (Fig. 1-10) or metallic implants. The implication for regional anesthesia is that tissues in the region of the shadow cannot be visualized. One benefit of this artifact is that the acoustic shadow of the block needle helps in identifying its location.

6. **Acoustic enhancement**

   Acoustic enhancement results when the ultrasound beam passes through a low-attenuating structure resulting in brighter echoes from the deeper tissues. It is commonly seen deep to fluid-filled structures such as blood vessels. The increased brightness may saturate the display and make it difficult to identify nerves posterior to large blood vessels. A common example is when one visualizes the posterior cord of the brachial plexus at the paracoracoid (lateral infraclavicular fossa) location. The bright echoes posterior to the axillary artery (second part) and deep to the pectoralis major and minor muscles may be confused as the posterior cord (Fig. 1-20).

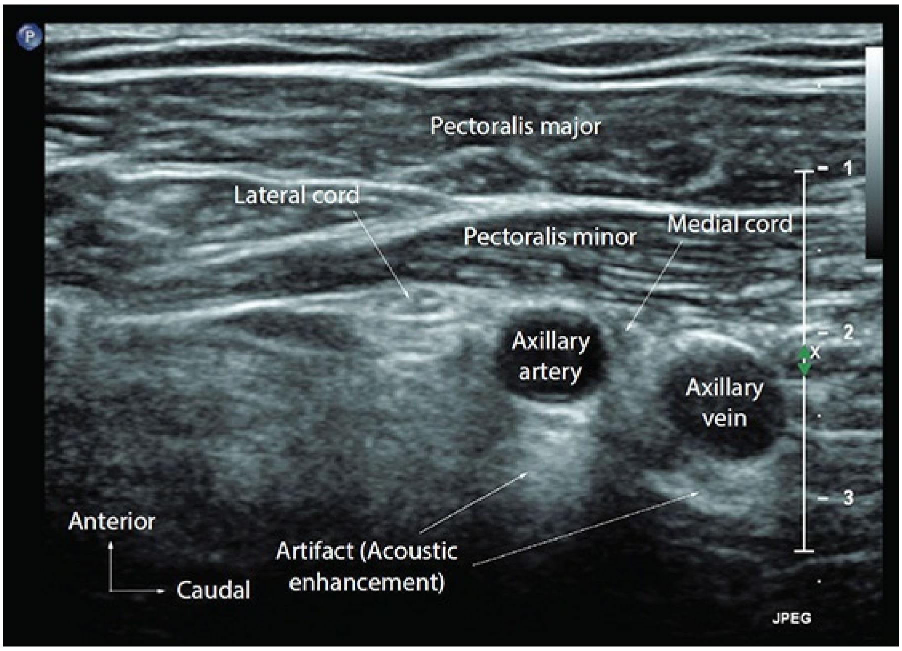

FIGURE 1-20 Acoustic enhancement seen posterior to the axillary artery and vein during an ultrasound guided infraclavicular brachial plexus block. The bright echoes posterior the axillary artery may be confused as the posterior cord.

Imaging the Challenging Patient

The Elderly Patient

Muscle fibers become hyperechoic with age (Fig. 1-21) due to muscle atrophy and infiltration by fat and connective tissue. The hyperechoic muscle is more likely to reflect the ultrasound beam and reduce penetration of deeper structures. Reduced contrast resolution between the