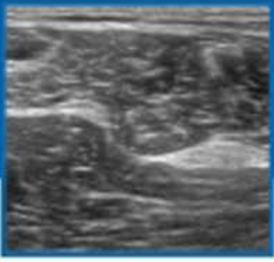
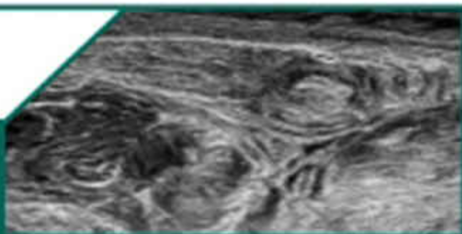
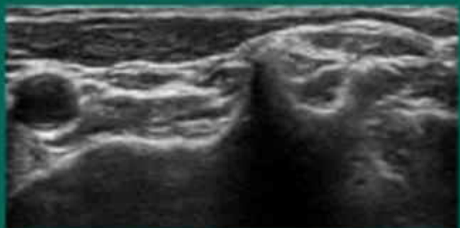
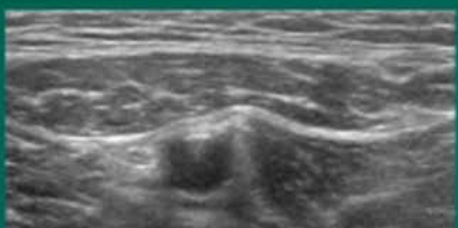



Third Edition

Atlas of Ultrasound-Guided Regional Anesthesia

Andrew T. Gray

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Third Edition

Atlas of Ultrasound-Guided Regional Anesthesia

Andrew T. Gray, MD, PhD

Professor of Clinical Anesthesia
Department of Anesthesia and Perioperative Care
School of Medicine
University of California, San Francisco
Staff Anesthesiologist
San Francisco General Hospital
San Francisco, California

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1600 John F. Kennedy Blvd.
Ste 1800
Philadelphia, PA 19103-2899

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To my family of writers: Mary, Sarah, Alex, and Anna.

Preface

The third edition of *Atlas of Ultrasound-Guided Regional Anesthesia* marks a change in format. There are now many new chapters by contributing authors that vastly improve and expand the section of topics from what would be possible with a single-author text. A wide variety of newly described techniques are presented in this edition, and chapters from the previous editions underwent extensive editing and updating. The new chapters are mostly dedicated to blocks in the trunk and head and neck regions. The emphasis on safety continues, with a detailed contributed chapter that reviews large studies of rare events. Also included is a chapter on limited resources that discusses techniques and alternatives in different clinical settings.

We have tried to present clear and concise summaries of suggested techniques so that readers will have the confidence and background they need to begin using the interventional procedures. Wide fields of view, long axis views, three-dimensional imaging, and step-by-step instruction are all used to improve the educational format and illustrate anatomic structures that lie near or outside the conventional two-dimensional field of imaging. Where appropriate, chapters have additional sonograms that illustrate variations of normal anatomy that one may encounter in clinical practice. New videos show the dynamics of interventional acute pain medicine in stunning detail. All the chapters highlight recent advances and techniques in the rapidly changing field of ultrasound-guided regional anesthesia.

Very special thanks to Allegra Greher (artwork), Tin-na Kan (sciatic nerve blocks), David Mai (catheters), Ed Mathews (information technology), Stefan Simon (intercostal nerve blocks), Robin Stackhouse and Susan Yoo (figures and media production), and Ranier Litz and Tim Maecken (organizing the USRA Symposia at which much of this educational material was presented and discussed). We are grateful to the anesthesiologists, CRNAs, anesthesia technicians, and perioperative nurses at Kaiser Permanente hospitals in Oakland, Richmond, and San Francisco, California for their help with the catheter sonograms and video clips.

Andrew T. Gray, MD, PhD

Contributors

Michael J. Barrington, MBBS, FANZCA, PhD
Associate Professor
Faculty of Medicine, Dentistry and Health Sciences
University of Melbourne Medical School
Parkville, Victoria, Australia;
Department of Anaesthesia and Acute Pain Medicine
St. Vincent's Hospital Melbourne
Fitzroy, Victoria, Australia.
Chapter 74: Safety: Practical Techniques to Prevent Complications During Ultrasound-Guided Nerve Blocks

Gerald Dubowitz, MD
Associate Professor
Department of Anesthesia and Perioperative Care
University of California, San Francisco
San Francisco, California
Chapter 75: Regional Anesthesia in Resource-Constrained Environments

Urs Eichenberger, MD
Balgrist University Hospital
Chair, Department of Anaesthesia
Zürich, Switzerland
Chapter 58: Ilioinguinal and Iliohypogastric Nerve Blocks

Hesham Elsharkawy, MD, MBA, MSc
Staff Departments of General Anesthesia and Pain Management, Outcomes Research
Assistant Professor of Anesthesiology
CCLCM of Case Western Reserve University
Cleveland, Ohio
Chapter 60: Quadratus Lumborum Blocks

Jeffrey Ghassemi, MD, MPH
Assistant Clinical Professor
Department of Anesthesia and Perioperative Care
University of California, San Francisco
San Francisco, California;
Chief of Anesthesia
Diablo Service Area
The Permanente Medical Group
Kaiser Petrmanente
Walnut Creek, California
Chapter 42: The Adductor Canal Block

Andrew T. Gray, MD, PhD
Professor of Clinical Anesthesia
Department of Anesthesia and Perioperative Care
School of Medicine
University of California, San Francisco;
Staff Anesthesiologist
San Francisco General Hospital
San Francisco, California

Manfred Greher, MD, MBA
Hospital of the Sacred Heart of Jesus
Vienna, Austria
Chapter 69: Greater Occipital Nerve Block

Peter Hebbard, MD
Department of Anesthesia
University of Melbourne
Wangaratta, Austalia
Chapter 59: Transversus Abdominis Plane Blocks

Jens Kessler, MD
Department of Anesthesiology
University Hospital Heidelberg
Heidelberg, Germany
Chapter 73: Stellate Ganglion Block

Manoj Kumar Karmakar, MD, FRCA, DA (UK), FHKCA, FHKAM
Professor, Consultant Anaesthesiologist and Director of Paediatric Anaesthesia
Department of Anaesthesia and Intensive care
The Chinese University of Hong Kong
Prince of Wales Hospital
Shatin, Hong Kong, China
Chapter 61: Thoracic Paravertebral Block

Bradley Lee, MD
Department of Anesthesia and Perioperative Care
University of California, San Francisco
San Francisco, California
Chapter 47: Posterior Femoral Cutaneous Nerve Block

Michael S. Lipnick, MD
Assistant Professor
Department of Anesthesia and Perioperative Care
University of California, San Francisco
San Francisco, California
Chapter 75: Regional Anesthesia in Resource-Constrained Environments

L. Stephen Long, MD
Pediatric Anesthesiologist
Children's Anesthesia Medical Group
UCSF Benioff Children's Hospital Oakland
Oakland, California
Chapter 62: Pudendal Nerve Block in Children

Daniel A. Nahrwold, MD
Assistant Professor
Department of Anesthesia and Perioperative Care
University of California, San Francisco
San Francisco, California
Chapter 14: Ultrasound-Guided Continuous Peripheral Nerve Blocks

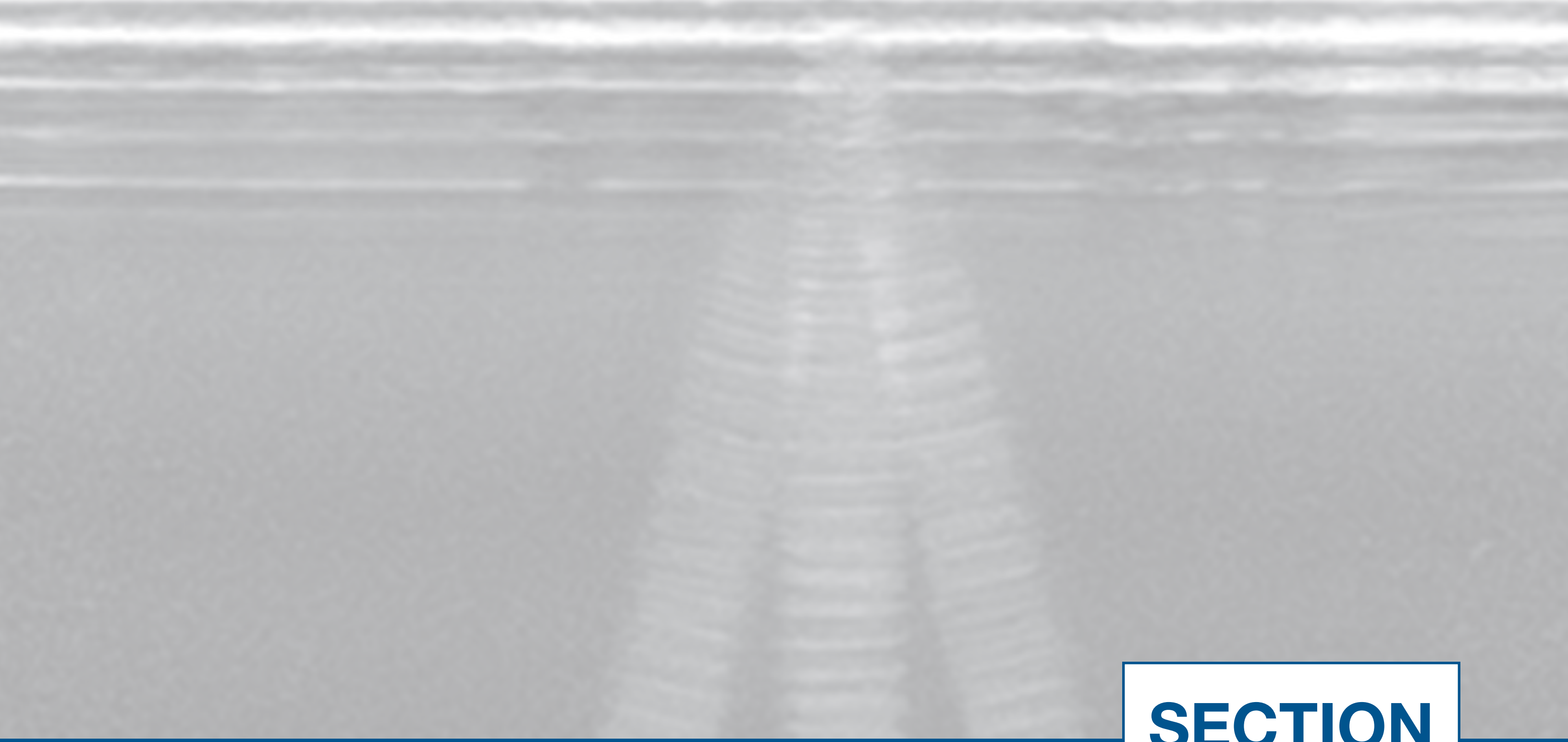
Contributors

Ronald Seidel, MD
Department of Anaesthesiology and Intensive Care Medicine
HELIOS Medical Center Schwerin
Schwerin, Germany
Chapter 72: Cervical Plexus Block

Agnes Wabule, MMED
Head of Department
Department of Anesthesia and Critical Care
Mulago Hospital
Kampala, Uganda
Chapter 75: Regional Anesthesia in Resource-Constrained Environments

Daniel M. Wong, MBBS, FANZCA
Honorary Clinical Senior Fellow
University of Melbourne Medical School
Parkville, Victoria, Australia;
Department of Anaesthesia and Acute Pain Medicine
St. Vincent's Hospital Melbourne
Fitzroy, Victoria, Australia
Chapter 74: Safety: Practical Techniques to Prevent Complications During Ultrasound-Guided Nerve Blocks

Video Contents



SECTION 1

Introduction to Ultrasound Imaging

CHAPTER 1

Ultrasound

See Video 1.1 on ExpertConsult.com.

Ultrasound waves are high-frequency sound waves generated in specific frequency ranges and sent through tissues.[1] How sound waves penetrate a tissue depends on the range of the frequency produced. Lower frequencies penetrate deeper than high frequencies do. The frequencies for clinical imaging (1 to 70 MHz) are well above the upper limit of normal human hearing (15 to 20 KHz). Wave motion transports energy and momentum from one point in space to another without transport of matter. In mechanical waves (e.g., water waves, waves on a string, and sound waves), energy and momentum are transported by means of disturbance in the medium because the medium has elastic properties. Any wave in which the disturbance is parallel to the direction of propagation is referred to as a longitudinal wave. Sound waves are longitudinal waves of compression and rarefaction of a medium such as air or soft tissue. *Compression* refers to high-pressure zones, and *rarefaction* refers to low-pressure zones (these zones alternate in position).

As the sound passes through tissues, it is absorbed, reflected, or allowed to pass through, depending on the echodensity of the tissue. Substances with high water content (e.g., blood, cerebrospinal fluid) conduct sound very well and reflect very poorly and thus are termed *echolucent*. Because they reflect very little of the sound, they appear as dark areas (hypoechoic). Substances low in water content or high in materials that are poor sound conductors (e.g., air, bone) reflect almost all the sound and appear very bright (hyperechoic). Substances with sound conduction properties between these extremes appear darker to lighter, depending on the amount of wave energy they reflect.

Audible sounds spread out in all directions, whereas ultrasound beams are well collimated. The frequency of sound does not change with propagation unless the wave strikes a moving object, in which case the changes are small. The product of the frequency and wavelength of sound waves is the wave speed. Because the speed of sound in soft tissue is nearly constant, higher-frequency sound waves have shorter wavelengths. Two adjacent structures cannot be identified as separate entities on an ultrasound scan if they are less than one wavelength apart. Therefore sound wave frequency is one of the main determinants of spatial resolution of ultrasound scans.

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CHAPTER 2

Speed of Sound

See Video 1.1 on ExpertConsult.com.

The speed of sound is determined by properties of the medium in which it propagates. The sound velocity equals $\sqrt{(B/rho)}$, where *B* equals the bulk modulus and *rho* equals density. The bulk modulus is proportional to stiffness. Thus stiffness (change in shape) and wave speed are related. Density (weight per unit volume) and wave speed are inversely related. The speed of sound in a given medium is essentially independent of frequency.

Because the velocity of sound in soft tissue is 1540 m/s, 13 microseconds elapse for each centimeter of tissue the sound wave must travel (the back-and-forth time of flight). Speed-of-sound artifacts relate to both time-of-flight considerations and refraction that occurs at the interface of tissues with different speeds of sound.[1-3]

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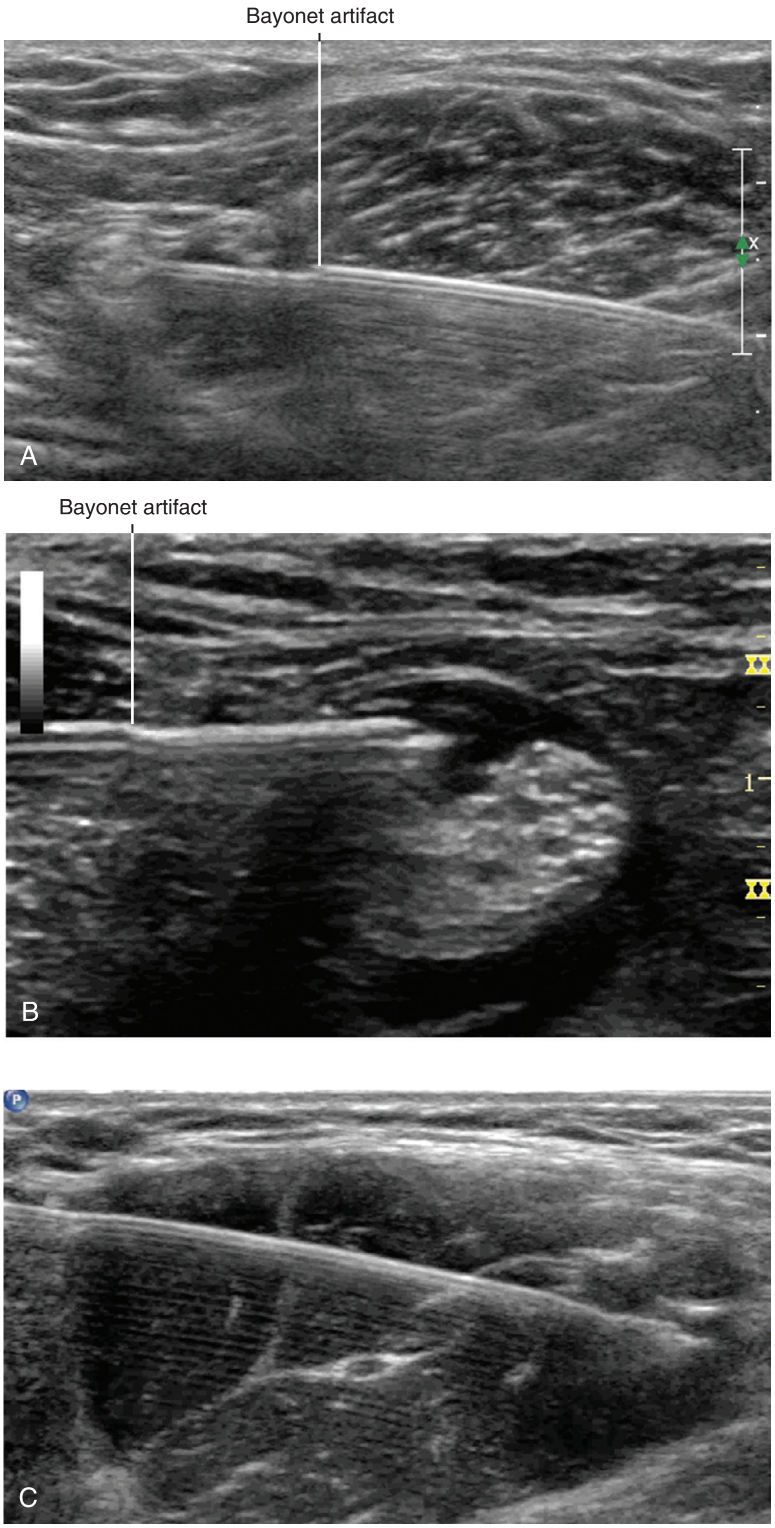

FIGURE 2.1 Bayonet artifacts during popliteal block (A and B). Because the speed of sound is not necessarily homogeneous in soft tissue, the needle can sometimes appear to bend, similar to a bayonet. Actual mechanical bending of the needle typically appears as gentle bowing of the needle (C).

Attenuation

CHAPTER 3

See Video 1.1 on ExpertConsult.com.

Attenuation is a decrease in wave amplitude as it travels through a medium. The attenuation of ultrasound in soft tissue is approximately 0.5 to 0.75 dB/(MHz-cm), indicating that the extent of attenuation depends on the distance traveled and the frequency of insonation. The units of the attenuation coefficient directly show the greater attenuation of high-frequency ultrasound beams. In soft tissue, 80% or more of the total attenuation is caused by absorption of the ultrasound wave, thereby generating heat.

Time gain compensation (TGC) adjusts for attenuation of an ultrasound beam as a function of depth. When TGC is properly adjusted, images of similar reflectors appear the same regardless of depth.

An acoustic shadow is said to exist when a localized object reflects or attenuates sound to impede transmission. Bone is a strong absorber of ultrasound waves. Therefore shadowing occurs deep to bony structures ("bone shadow").

When a nonattenuating fluid (e.g., blood or injected local anesthetic) lies within an attenuating sound field (e.g., soft tissue), enhancement of echoes deep to the fluid occurs. This phenomenon, originally described as posterior acoustic enhancement (also called increased through-transmission), is due to lack of absorption of the sound waves by the fluid.[1] This attenuation artifact is a potential source of problems, especially during regional blocks where nerves are situated close to blood vessels.

Clinical Pearls

- In general, the highest frequency capable of adequate penetration to the depth of interest should be used for imaging.
- Decibels (dB) are a relative logarithmic measure of sound wave intensity.

Reference

1. Filly RA, Sommer FG, Minton MJ. Characterization of biological fluids by ultrasound and computed tomography. *Radiology*. 1980;134:167–171.

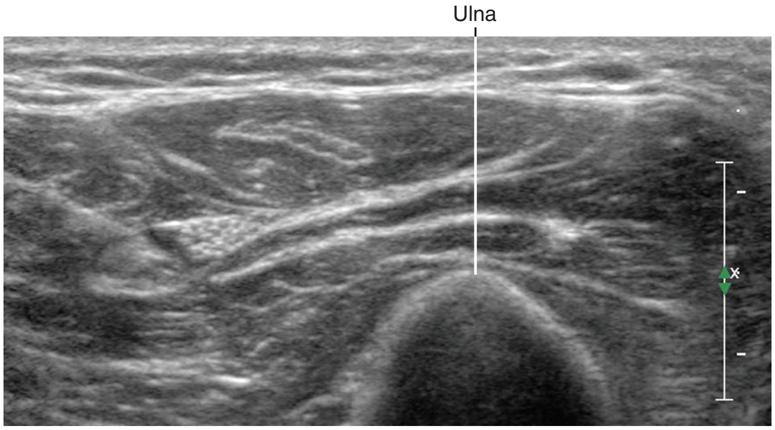

FIGURE 3.1 Acoustic shadowing by bone. In this sonogram from the forearm, the acoustic shadowing by the ulna is evident. The bright cortical line of the surface of the bone is followed by extinction of the sound wave below.

Reflection

CHAPTER 4

See Video 1.1 on ExpertConsult.com.

Ultrasonography measures the amplitude of the return echo as a function of time.[1] Sound waves are reflected at the interface of tissues with different acoustic impedances. The acoustic impedance (kg/[m^2-s]) is the product of the density (kg/m^3) and velocity (m/sec). The extent of reflection is governed by the reflection coefficient: $R = (Z1 - Z2)/(Z1 + Z2)$. If $Z1 = Z2$, there is no reflected wave.[2] Ultrasound characteristics of biologic tissue and interventional materials are summarized in Table 4.1.

Reflections off a smooth surface are called *specular*. If two specular reflectors are close to each other, reverberation within the sound field can result, displayed as parallel, equally spaced lines deep to the reflectors. Csomet-tail artifact, which is a form of reverberation artifact, is caused by multiple internal reflections from a small, highly reflective interface.[3,4]

Clinical Pearls

- The normal pleural line is thin and smooth, which generates a few comet-tail artifacts (between one and three artifacts per intercostal space scan). In the presence of parenchymal lung disease, the pleural line is irregular and thickened, generating many more comet-tail artifacts.[5]
- No comet-tail artifact is observed from the lung when pneumothorax is present.
- Hyperechoic reverberation artifacts are seen with metallic foreign bodies such as block needles.

TABLE 4.1 Ultrasound Characteristics of Biologic Tissue and Interventional Materials

Substance	Velocity (m/s)	Attenuation (dB/[MHz-cm])	Impedance (mrayls × 10^{-6})
Air	330	7.5	0.0001
Water	1480	0.0022	1.5
Soft tissue	1540	0.75	1.7
Blood	1575	0.15	1.6
Bone	4080	15	8
Stainless steel	5790	0.2	47

Data from Ziskin MC. Fundamental physics of ultrasound and its propagation in tissue. *Radiographics*. 1993;13:705–709; Ziskin MC, Thickman DI, Goldenberg NJ, Lapayowker MS, Becker JM. The comet tail artifact. *J Ultrasound Med*. 1982;1:1–7; Gawdzinska K. Investigation into the propagation of acoustic waves in metal. *Metalurgija*. 2005;44:125–128; Smith SW, Booi RC, Light ED, Merdes CL, Wolf PD. Guidance of cardiac pacemaker leads using real time 3D ultrasound: feasibility studies. *Ultrason Imaging*. 2002;24:119–128.

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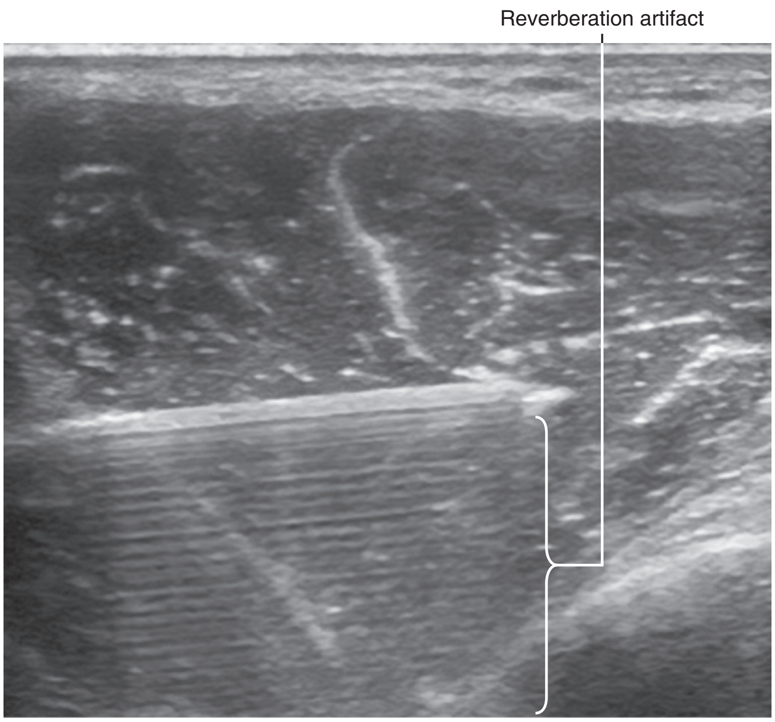

FIGURE 4.1 Reverberation artifact from a block needle placed nearly parallel to the active face of the transducer.

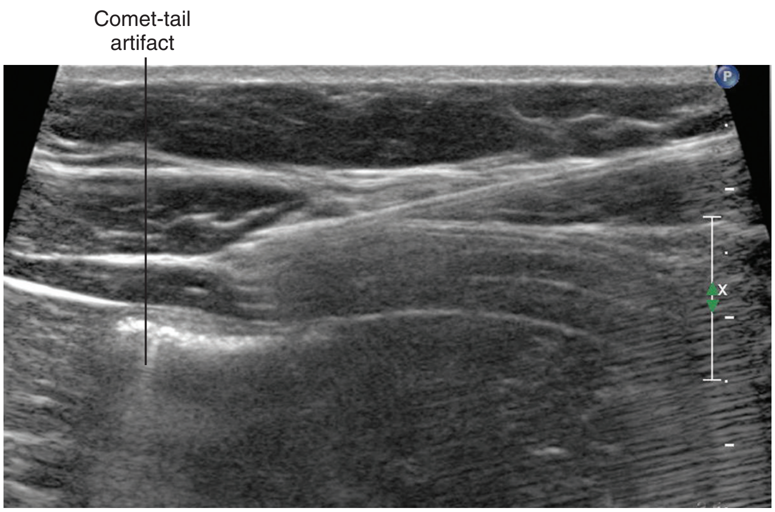

FIGURE 4.2 Comet-tail artifact from the peritoneum during rectus sheath block. The peritoneum and pleura have similar appearances on ultrasound scans.

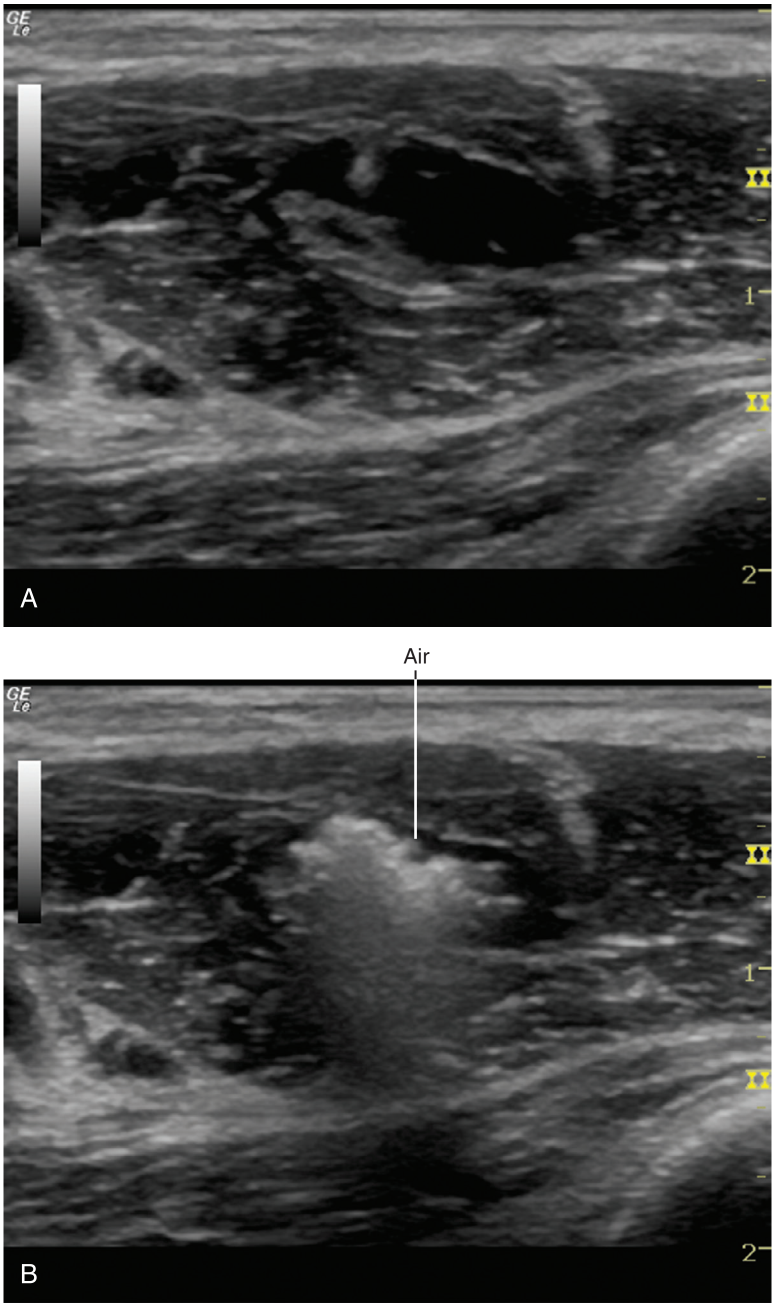

FIGURE 4.3 A strong echo and acoustic shadowing are observed when air is inadvertently injected during musculocutaneous nerve block in the axilla. Sonograms before injection (A) and after injection (B) are shown.

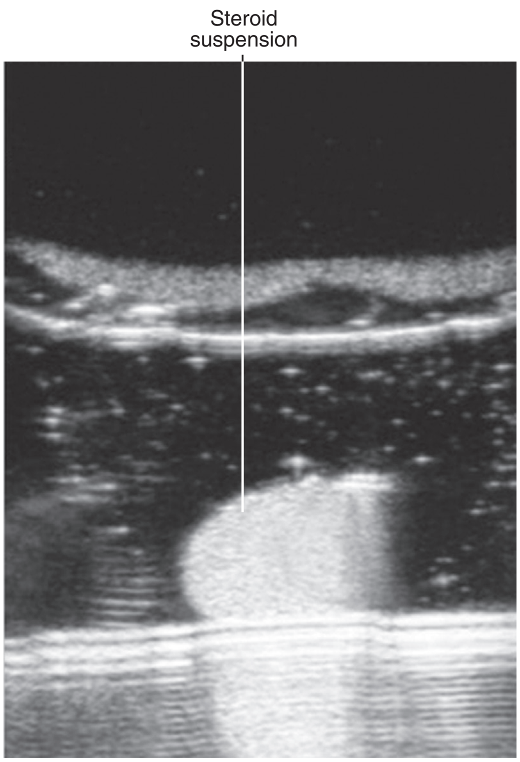

FIGURE 4.4 Acoustic properties of a steroid suspension. Although the local anesthetic injected for most regional blocks is anechoic, the particles of this steroid suspension are sufficiently large to produce a strong echo.

Beam Width (Slice Thickness)

CHAPTER 5

See Video 1.1 on ExpertConsult.com.

Ultrasound systems assume all reflectors lie directly along the main axis of the ultrasound beam (i.e., the acoustic axis or central ray)[1]; however, ultrasound beams have a finite size. The out-of-plane beam width (slice thickness) can be measured with a diffuse scattering plane.[2] The plane is oriented at a 45-degree angle so that the displayed echoes are equal to the out-of-plane echoes. Ultrasound beams can be focused to reduce the out-of-plane beam width and thereby improve image quality.

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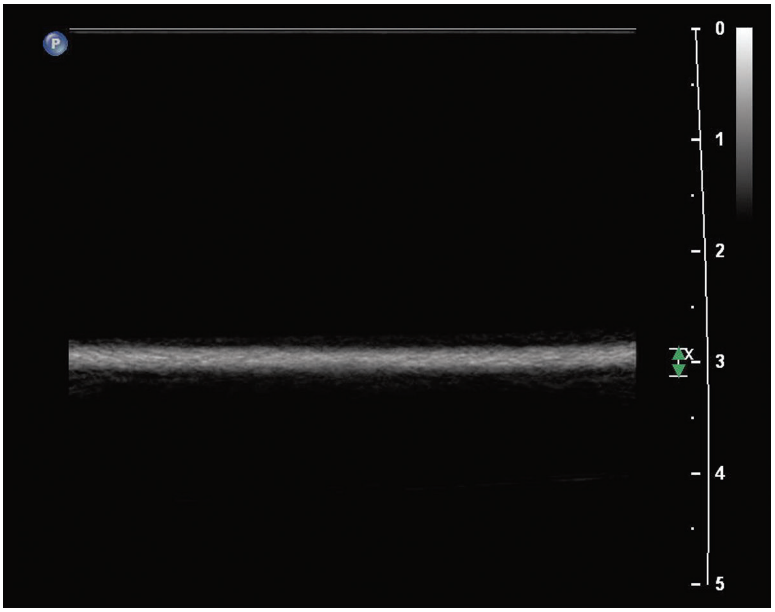

FIGURE 5.1 Out-of-plane slice thickness. Ultrasound scan of a diffuse scattering plane (a sheet of sandpaper).

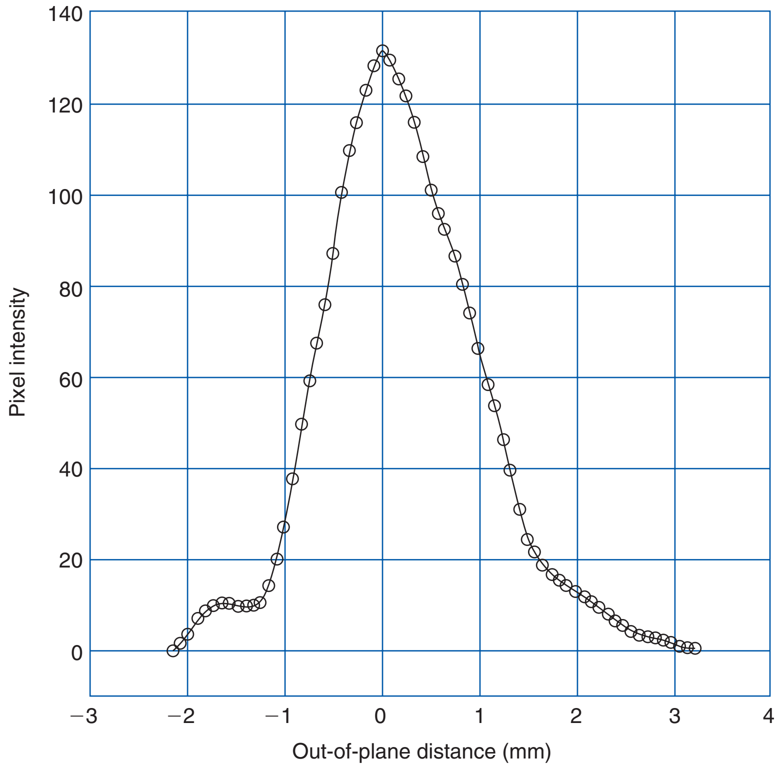

FIGURE 5.2 The beam profile is shown as a function of the distance from the central ray. Because needle diameters are substantially less than those of the slice plane, a strong relationship between needle diameter and visibility is expected.

Anisotropy

CHAPTER 6

See Video 1.1 on ExpertConsult.com.

Isotropic means equal in all directions. Anisotropic implies angle dependence. The latter term has been used to indicate the change in amplitude of received echoes from a structure when the angle of insonation is changed. Anisotropy is a discriminating feature between nerves and tendons. Tendons are more anisotropic than nerves are, meaning that smaller changes in angle (approximately 2 degrees) alter the echoes from tendons than the changes in angle (approximately 10 degrees) that alter the echoes from nerves. The anisotropy of nerves also is important because during interventions it can be challenging to maintain nerve visibility while manipulating the transducer to image the block needle.[1] With training, practitioners learn to naturally manipulate the transducer to fill in the received echoes from nerves. The amplitude of the received echoes from peripheral nerves is usually largest when the sound beam is perpendicular to the nerve path. Other structures, such as muscle, also exhibit anisotropy.[2]

Clinical Pearls

- Anisotropy means that the backscatter echoes from a specimen depend on the directional orientation within the sound field.
- Anisotropy can be quantified by specifying the transducer frequency and the decibel change in backscatter echoes with perpendicular and parallel orientation of the specimen.
- Nerves, tendons, and muscle all exhibit anisotropy. Of these structures, tendon echoes are the most sensitive to transducer manipulation.

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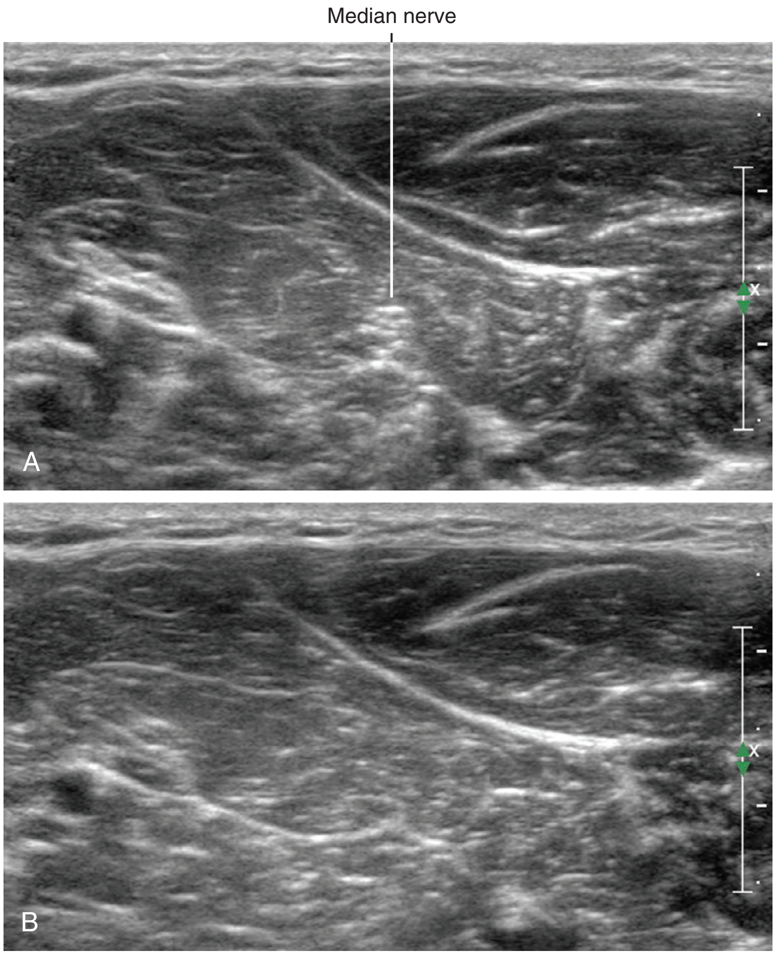

FIGURE 6.1 Anisotropy of the median nerve (A and B). With inclination of the transducer (tilting), the received echoes from the median nerve disappear.

CHAPTER 7

Spatial Compound Imaging

See Video 1.1 on ExpertConsult.com.

In conventional sonography, tissue is insonated from a single direction. Spatial compound imaging combines multiple lines of sight to form a single composite image at real-time frame rates. The ultrasound beam is steered by a different set of predetermined angles, typically within 20 degrees from the perpendicular.

One benefit of the use of spatial compound imaging is the reduction of angle-dependent artifacts (Table 7.1). *Speckle* is the granular appearance of a sonographic image that results from scattering of the ultrasound beam from small tissue reflectors. This speckle artifact results in the grainy appearance observed on sonograms, representing noise in the image. Improved image quality may be obtained by using spatial compound imaging, which can reduce speckle noise.

There is a central triangular region of overlap within the field of view where all angles mesh together for full compounding. The corners of the image receive only a subset of all the lines of sight; therefore not all the benefits of spatial compounding are manifest. Some machines allow the stray lines of sight (those off the rectangular field of view) to form a trapezoidal image format. This is sometimes useful to view the approaching needle with in-plane technique.

Spatial compound imaging was first designed to eliminate angle-dependent artifacts.[1] This can be accomplished with a narrow range of beam angles. The larger the range of angles subtended by spatial compounding, the smaller the region within the field of imaging that will receive all the lines of sight (i.e., the region of full compounding).

Ultrasound imaging near bone may be improved by spatial compound imaging. This has relevance to imaging for some blocks (e.g., neuraxial, paravertebral, lumbar plexus, intercostals, sacroiliac joint). Although ultrasound waves cannot penetrate mature bone (even with low-frequency ultrasound), spatial compound imaging allows better definition of the bone surface.

Linear test tool images can be used to reveal the number of lines of sight used in spatial compound imaging. These images are generated with a smooth metal surface, such as that of a paper clip, solid metal stylet, or a US nickel. Metal is used because it is relatively nonattenuating,

TABLE 7.1 Advantages and Disadvantages of Spatial Compound Imaging

Advantages	Disadvantages
Reduction of angle-dependent artifacts (e.g., posterior acoustic enhancement and speckle)	Frame averaging (persistence or motion blur effect)
Needle tip imaging	Limited range of angles (typically <20 degrees)
Nerve border definition	
Fascia contours	
Imaging around bone	
Wider field of view with stray lines of sight	

yet produces an echo. Smooth metal is used so that the test tool does not damage the transducer. For these measurements, high receiver gain and a single focal zone near the surface are used. As long as the test tool contact is less than the receiver aperture, the width of the displayed echoes will not change.

Clinical Pearls

- The use of spatial compound imaging can improve imaging of nerve borders and the block needle tip.
- One potential disadvantage of compound imaging is that needle reverberations occur over a broader range of angles and can prevent imaging of deeper structures.
- Compound imaging is being developed for both linear and curved arrays.
- Sliding the transducer along the known course of the nerve is a well-established technique to improve small nerve imaging. However, frame rate reduction that occurs with spatial compound imaging can cause problems with this technique.
- If compound imaging is not an advantage for a particular imaging situation, it can be turned off.

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1. Baad M, Lu ZF, Reiser I, Paushter D. Clinical significance of US artifacts. *Radiographics*. 2017;37:1408–1423.

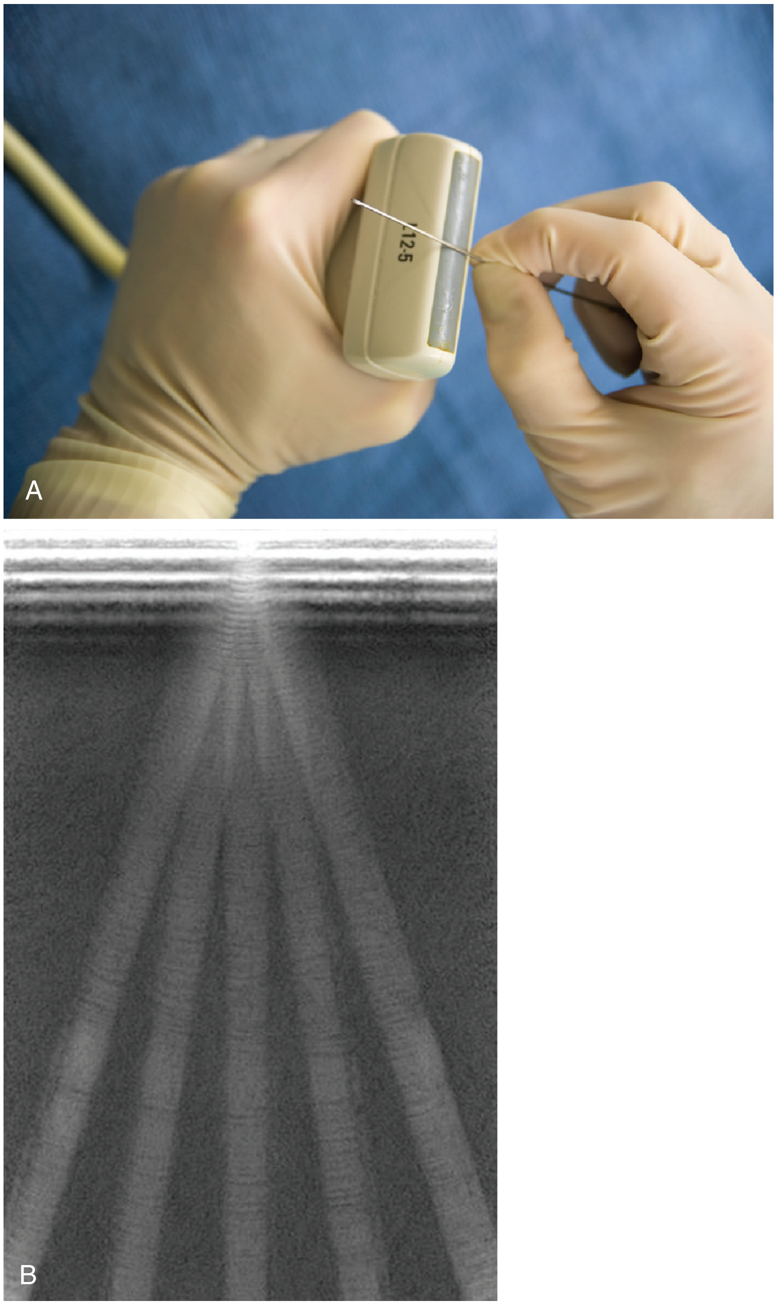

FIGURE 7.1 Spatial compound imaging. Some forms of ultrasound imaging use multiple lines of sight by electronically steering the beam to different angles. This sonogram was obtained by placing a linear array test tool (the solid metal stylet of a 17-gauge epidural needle) over the active face of the transducer to isolate a single element (A and B). The displayed test tool image consists of the receiver apertures of the transducer. In this case, five lines of sight are used to form a compound image.

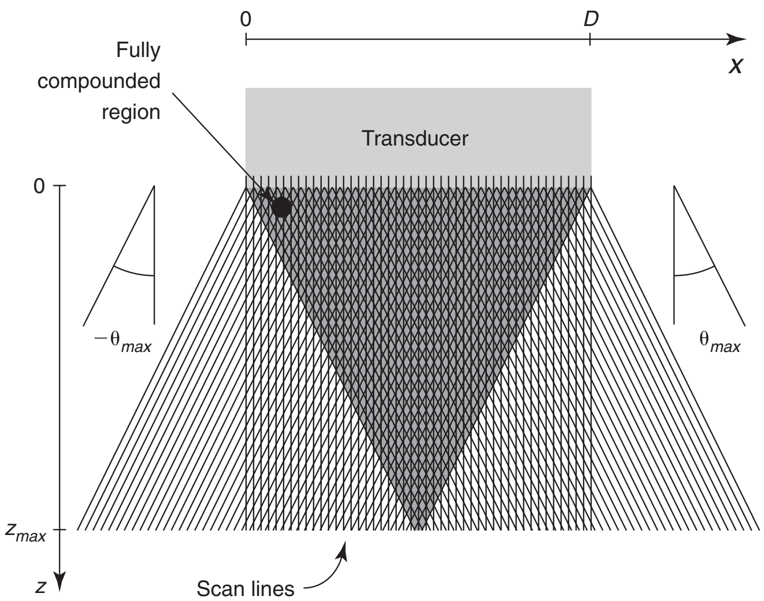

FIGURE 7.2 Conceptual illustration of transducer and associated scan lines for recording of three single-angle images. (Adapted from Jespersen SK, Wilhjelm JE, Sillesen H. In vitro spatial compound scanning for improved visualization of atherosclerosis. *Ultrasound Med Biol*. 2000;26:1357–1362.)

CHAPTER 8

Doppler Imaging

See Video 1.1 on ExpertConsult.com.

The Doppler shift is the change in frequency of sound when the sound wave strikes a moving object. This means the frequencies of the transmitted and reflected sound waves are not the same. Doppler shifts in clinical imaging are in the audible range (±10 KHz). Red blood cells are the primary reflectors that produce Doppler shifts. Ultrasound machines can color-encode the mean velocity (color Doppler), variance within the sample volume (variance Doppler), and power spectrum of the frequency shift (power Doppler).[1]

The optimal spectral Doppler angle is 30 to 60 degrees. Doppler angles greater than 60 degrees result in small Doppler shifts. Doppler angles less than 30 degrees result in loss of signal due to refraction.

Aliasing (incorrect or ambiguous estimation of the velocity) occurs when the velocity scale is set too small relative to the actual velocities. Wraparound transition between positive and negative velocity on spectral Doppler tracings indicates aliasing; therefore the peak velocities are off scale and not accurately estimated. This occurs because the pulse repetition frequency is insufficiently low relative to the frequency of the Doppler signal (a consequence of the sampling or Nyquist theorem).

Color Doppler is traditionally shown with the Nyquist velocity limits. Color aliasing is displayed as reversed flow within laminar flow areas, with no intervening black stripe between them. With true flow reversal, the transition has an intervening black stripe, indicating no flow estimation. This narrow colorless area occurs because of the absence of a Doppler shift where flow is perpendicular to the angle of insonation.

Clinical Pearls

- Blood has a low ultrasound attenuation coefficient. Red blood cells are the primary reflectors within blood.
- In power Doppler the gain threshold can be adjusted to the level at which there is no observed signal in bone.[2]
- In low-flow states (e.g., heart failure or atrial arrhythmias), aggregates of red blood cells can cause spontaneous echo contrast within blood vessels.

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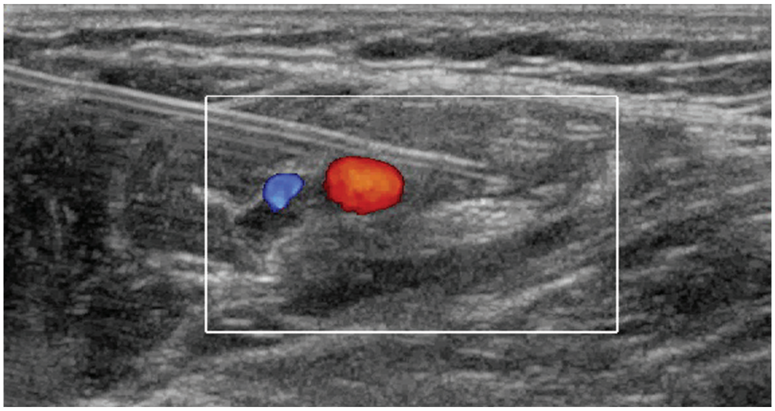

FIGURE 8.1 An example of color Doppler imaging during axillary block. A short-axis view of the neurovascular bundle is displayed.

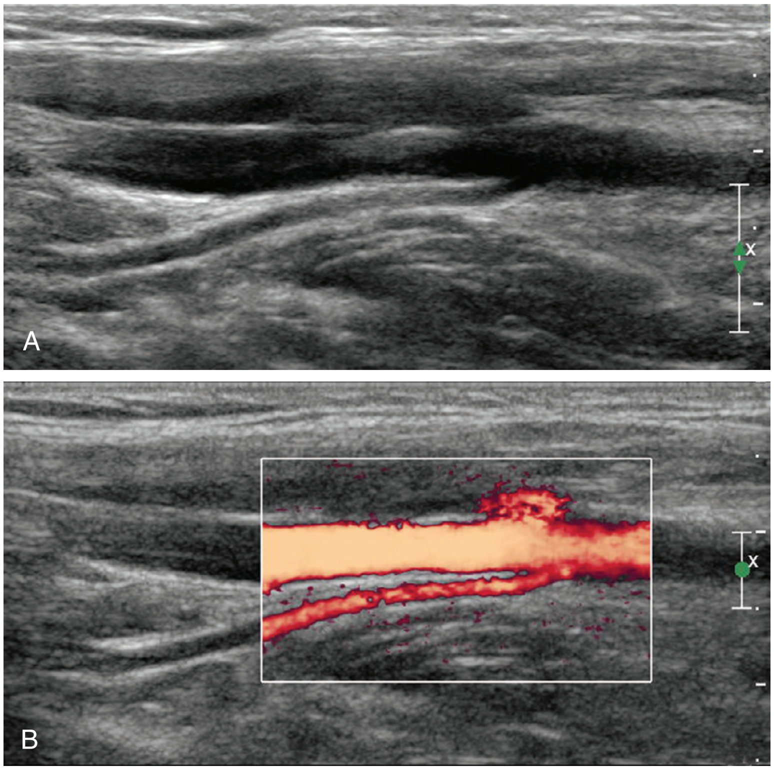

FIGURE 8.2 Long-axis view of the axillary artery and its profunda branch in conventional B-mode imaging (A) and with power Doppler (B).

CHAPTER 9

Ultrasound Transducers

See Video 1.1 on ExpertConsult.com.

Ultrasound transducers consist of arrays of piezoelectric crystals that produce high-frequency sound waves in response to an electrical signal. These crystals interconvert electrical and mechanical energy, allowing for both transmission and reception of sound waves. The piezoelectric element vibrates to produce ultrasound. Piezoelectric crystals change shape under the influence of an electric field. The thickness of the crystal and the propagation speed within determine the frequency. With some transducers, the sonographer can select different crystals within the assembly to produce a different frequency.

The first ultrasound transducers were made using natural piezoelectric crystals (quartz, Rochelle salts, tourmaline). Modern transducers use synthetic crystals, such as PZT (lead zirconate titanate), that have high density, velocity, and acoustic impedance.[1]

Linear arrays typically produce a rectangular image format. The piezoelectric crystals are arranged in a straight line. Curvilinear arrays produce images in sector format (that do not originate from a single point). The range of angles with curved arrays (typically, 0 to 60 degrees) is much larger than with beam steering for spatial compound imaging (typically, 0 to 20 degrees).

Most regional blocks are performed with linear transducers because the high scan line density produces the resolution necessary for direct nerve imaging. Small curved probes are useful for infraclavicular and suprascapular nerve blocks because working room is limited. With curved probes, inaccurate estimation of needle tip location can occur despite complete line-up due to the different angles at which the ultrasound beam hits the needle.

FIGURE 9.1 Ultrasound transducers for regional blocks. The photograph includes *(left to right)* broad linear, small footprint linear, curved, sector, and hockey stick transducers.

Reference

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CHAPTER 10

Transducer Manipulation

See Video 1.1 on ExpertConsult.com.

Nomenclature for transducer manipulation has been previously established.[1,2] Note that this nomenclature does not include specification of direction (e.g., rock back, rotate clockwise, tilt proximal). To control the transducer for interventions, the hands of the operator must be very close to the skin surface. The ulnar aspect of the transducer hand should rest on the skin of the patient.

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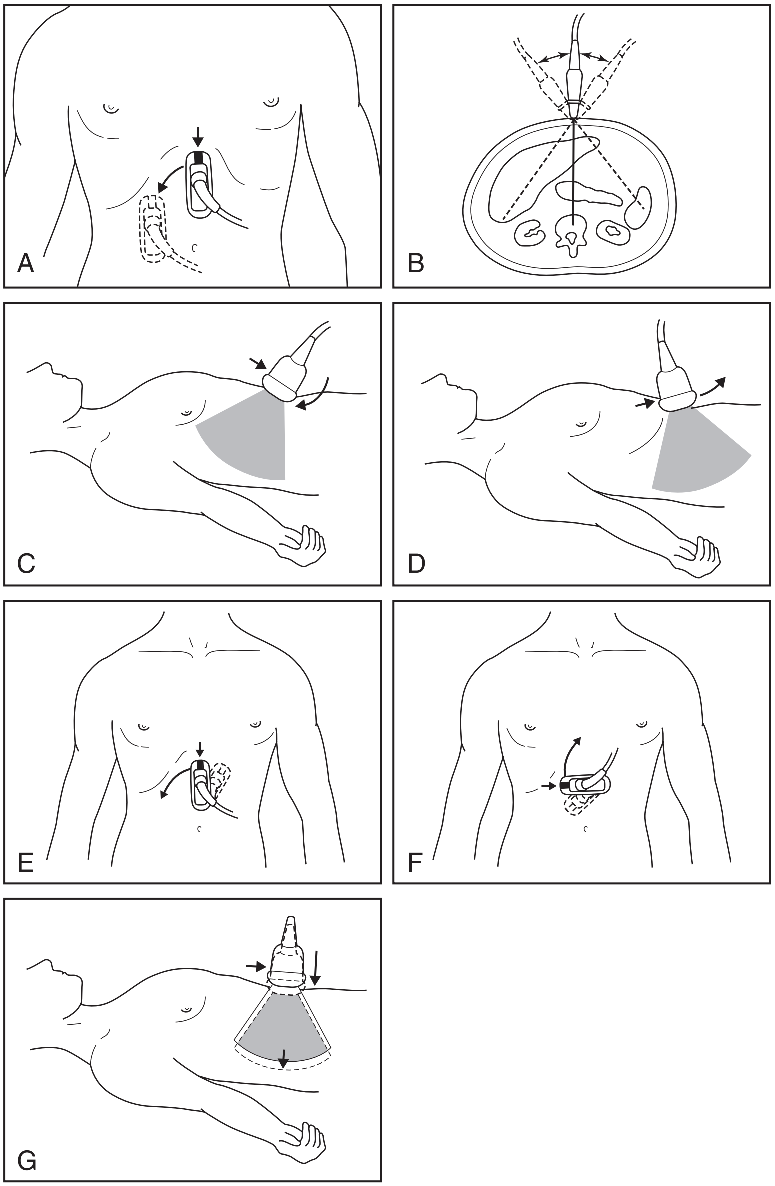

FIGURE 10.1 To optimally display anatomy for image presentation, the transducer must be manipulated. Transducer manipulation can be broken down into five basic movements: sliding (A), tilting (B), rocking (C and D), rotating (E and F), and compressing (G). Combining these movements allows for smooth scanning motion and anatomy visualization. (Adapted from AIUM technical bulletin. Transducer manipulation. American Institute of Ultrasound in Medicine. *J Ultrasound Med*. 1999;18:169–175.)

CHAPTER 11

Needle Imaging

See Video 1.1 on ExpertConsult.com.

Needle tip visibility is critical to the success and safety of regional block interventions. It is imperative to identify the needle tip before advancing the needle. The cut on the bevel is the best identifier of the needle tip for a beveled needle. Partial line-ups (so that the needle tip is not within the plane of imaging but some of the needle shaft is) are a source of false reassurance with in-plane technique. A number of factors have been reported to influence needle tip visualization under clinical imaging conditions (Table 11.1).

INSERTION ANGLE (ANGLE OF INSONATION)

Needle tip imaging is optimal when the needle is parallel to the active face of the transducer. The cleanest needle echo is from a conventional needle at or near parallel. One study found a linear correlation between angle of incidence (measured from 0 to 75 degrees) and the mean needle tip brightness.[1]

NEEDLE GAUGE

There are multiple advantages to using a large needle for regional block. Needles as large as 17 gauge have been used to improve needle tip visibility for regional blocks.[2] Alignment of a large needle is faster with in-plane technique. An additional advantage of a large needle is the ability to redirect the needle within the scan plane. A large needle tip can be used to displace structures (e.g., arteries or nerves) before advancing. The disadvantages of the large needle are patient discomfort and the consequences of unintended puncture (e.g., of vessels, nerves), which are typically worse. In addition, the soft tissue properties (tent and recoil) are more noticeable with large needles. With finer needle tips, the hand motion and needle tip motion are more closely matched, and it is easier to place a fine needle tip within a thin fascial plane.

BEVEL ORIENTATION

Needle bevel orientation is important for needle tip visibility (Table 11.2).[3] The bevel should be facing the transducer to enhance needle tip imaging.

TABLE 11.1 Factors Reported to Influence Needle Tip Visibility

Angle of insonation
Needle gauge
Bevel orientation
Receiver gain
Needle motion and test injections
Echogenic modifications
Spatial compound imaging

TABLE 11.2 Influence of Bevel Orientation on Needle Tip Visibility

Angle (Degrees)	Poor	Fair	Good
0	0.14	0.45	0.41
90	0.33	0.51	0.17
180	0.14	0.45	0.41
270	0.25	0.52	0.23

From Hopkins RE, Bradley M. In-vitro visualization of biopsy needles with ultrasound: a comparative study of standard and echogenic needles using an ultrasound phantom. *Clin Radiol*. 2001;56:499–502.

RECEIVER GAIN

The overall two-dimensional receiver gain should be reduced to improve visibility of the needle tip. However, a competing consideration is the visibility of other structures, such as the local anesthetic injection and blood vessels.

NEEDLE MOTION AND TEST INJECTIONS

Some clinicians move the needle slightly or use small-volume test injections of fluid (<1 mL) to improve the needle tip visibility.[4] Because regional anesthesia interventions are performed near reactive structures, if needle motion is used, it should be small and slow (avoid rapid jabbing motions, which may cause puncture or paresthesia).

ECHOGENIC MODIFICATIONS

McGahan roughened up the surface of needles with a No. 11 surgical blade to improve the needle tip visibility.[5] Historically, this was one of the first echogenic needle designs. When the angle of approach is more the 30 degrees, an echogenic needle is of benefit because the roughened surface sends echoes back to the transducer.[6]

SPATIAL COMPOUND IMAGING

With an increasing angle of incidence, the decrease in needle visibility is more pronounced for single-line ultrasound than for compound imaging. However, at angles of incidence of more than 30 degrees, the needle was barely visible with either method of imaging.[7]

Clinical Pearls

- Among specialized needles used for regional blocks, Hustead needle tips tend to have better ultrasound visibility.
- Side-port needles for regional block do not appear to exhibit isotropic diffraction, which has been reported to enhance the ultrasound visibility of similar needles.[8]
- Large-bore needles can be used as nerve retractors, pushing or pulling nerves out of the way of the advancing needle.
- Bevel orientation should be toward the nerve (so that the needle will pass the nerve rather than puncture it).
- When navigating the block needle between two nerves, the bevel should be rotated to face the closer of the two. This helps the block needle shoot the intervening gap and makes the closer nerve roll to the side as the needle is advanced. The same bevel orientation strategy can be used when placing the block needle between a nerve and an artery.

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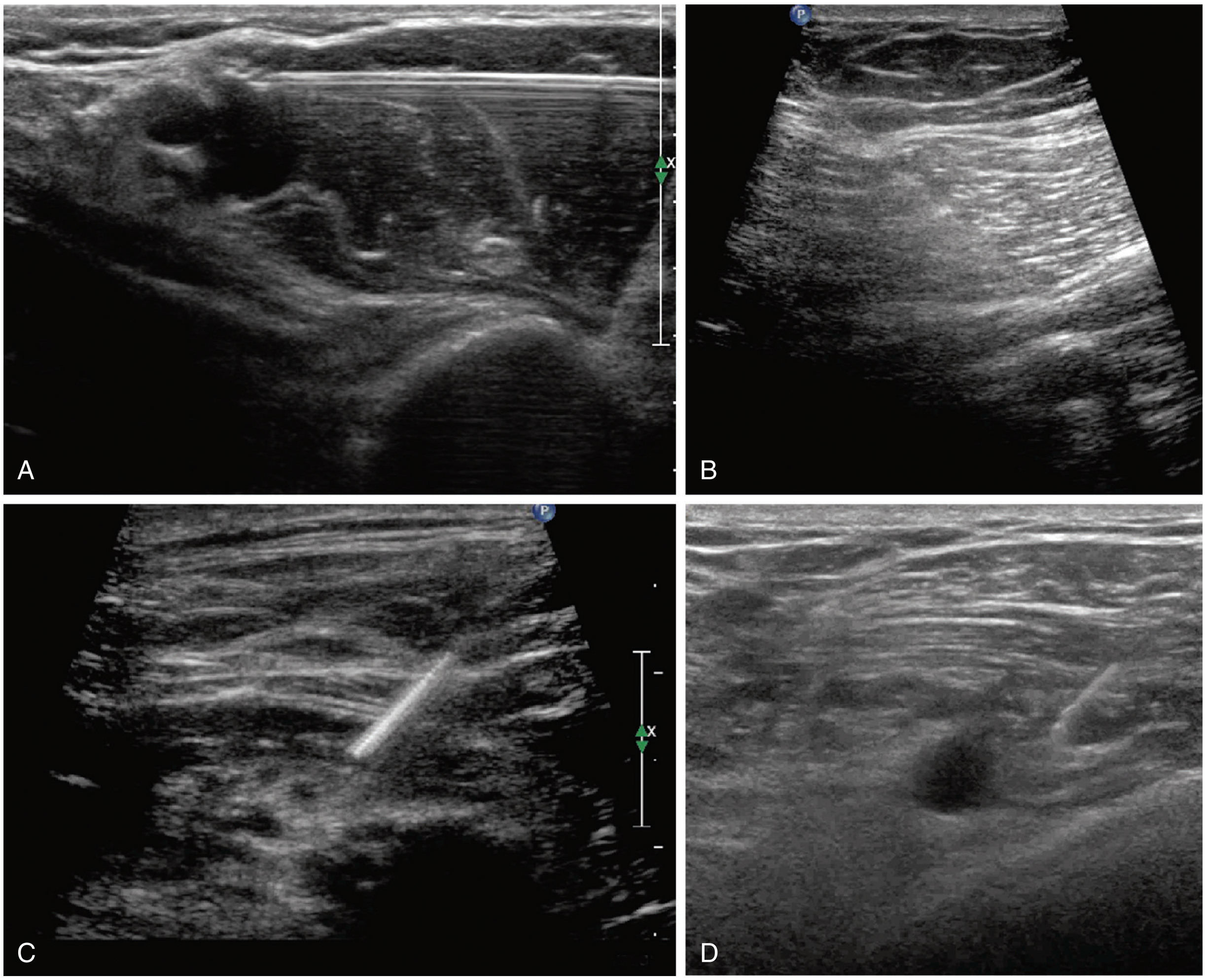

FIGURE 11.1 Influence of angle of insonation on needle tip visibility. When the needle is nearly parallel, the tip is easily identified (A). When the needle is at an angle, needle tip visibility is difficult (B). Echogenic needles can help improve needle tip visibility at steep angles under some clinical imaging conditions (C and D).

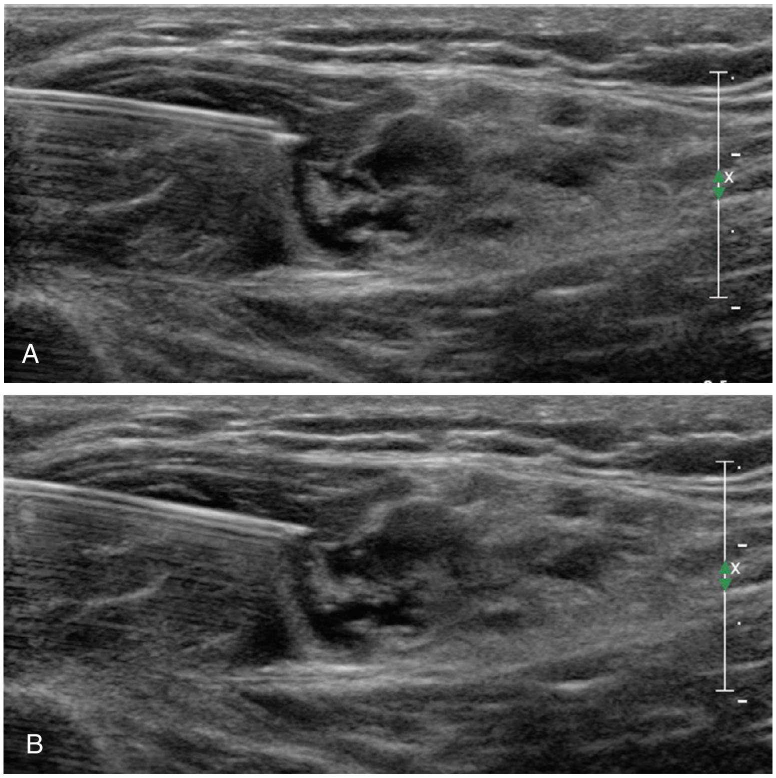

FIGURE 11.2 Influence of bevel orientation on needle tip visibility: bevel up (A) and bevel down (B).

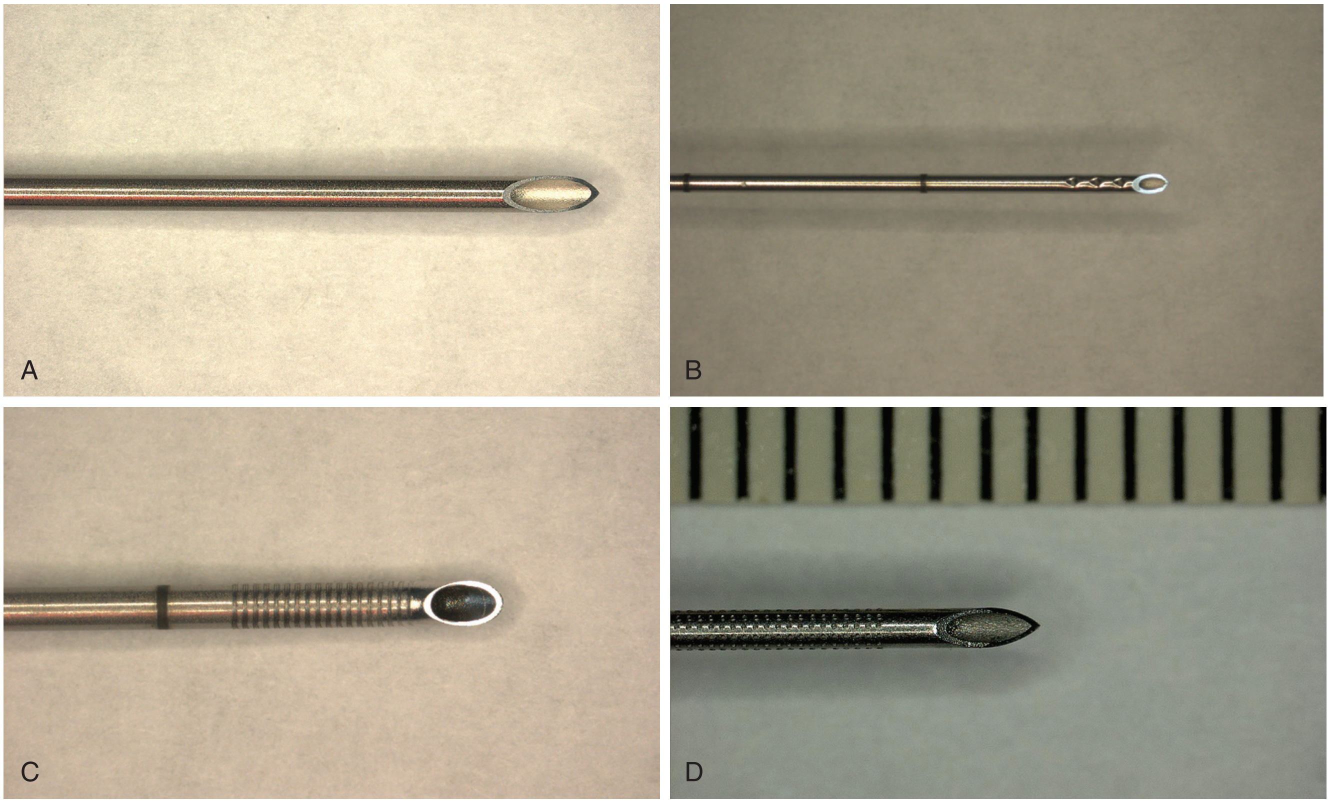

FIGURE 11.3 Photomicrographs of needles used for regional block. A plain conventional needle (A) and echogenic designs (B, C, and D) are shown. A smooth needle may not generate a recordable echo because its rounded shaft reflects most incident sound away from the source. A variety of textured surfaces are manufactured and marketed to improve needle tip detection on acquired sonograms.

CHAPTER 12

Approach and Techniques

See Video 1.1 on ExpertConsult.com.

OFFLINE MARKINGS

Offline techniques involve external skin markings from ultrasound scans without imaging during needle placement.[1] Changes in patient position, mobility of the skin, and dynamic changes with needle placement and injection limit the utility of this approach, but this approach can be used for neuraxial blocks. The skin adjacent to the sides of the transducer can be marked. Alternatively, a paper clip or solid metal stylet (preferably with dull ends) can be used to create artifact within the field to mark the position of the object. For this technique, spatial compound imaging can be turned off to enhance the artifact.[2] The M-mode center line can be used to facilitate offline markings in the center of the field.

ONLINE GUIDANCE

There are two basic approaches to online ultrasound guidance (imaging during the intervention). With the out-of-plane technique, the needle tip crosses the plane of imaging as an echogenic dot. With the in-plane approach, the entire tip and shaft of the advancing needle are visible.

OUT-OF-PLANE APPROACH

There are several advantages to the out-of-plane approach to regional block (Table 12.1). This approach is most similar to traditional approaches to regional block guided by nerve stimulation or palpation. Therefore the out-of-plane approach provides a natural transition from one form of guidance to another. The out-of-plane approach uses a shorter needle path than do in-plane approaches. If short-axis views of the nerve are used, an out-of-plane approach results in catheter placement that is guided along the path of the nerve. One disadvantage of the out-of-plane

TABLE 12.1 Comparison of Out-of-Plane and In-Plane Approaches

Approach	Advantages	Disadvantages
Out-of-plane (OOP)	Most similar to other approaches to regional block (nerve stimulation or palpation) Shorter needle path than with in-plane approaches Along the nerve path (catheters)	Unimaged needle path, crossing the plane of imaging without recognition
In-plane (IP)	Most direct visualization	Partial line-ups (creating a false sense of security when the needle tip is not correctly identified) Some unimaged needle path occurs with IP approach, but typically less than with OOP approach Longer paths and therefore more structures to cross with the block needle

approach is the extent of the unimaged needle path (structures that may lie short of or beyond the scan plane). If the needle tip crosses the scan plane without recognition, it can be advanced beyond the scan plane into undesired tissue.

IN-PLANE APPROACH

There are several advantages to the in-plane approach. It provides the most direct visualization of the needle tip and injection. The amount of unimaged needle path is typically small. The needle tip is visualized before advancement. One disadvantage is the long needle path, which results in more tissue for the needle to cross. Large-bore needles are often used with this approach to facilitate alignment. Partial line-ups (visualization of the needle shaft without visualization of the needle tip in the scan plane) create a false sense of security and therefore compromise safety of the technique.

External marks on the transducer can be used to initially guide needle placement for in-plane technique. However, the mechanical axis of the transducer and its acoustic axis are not always precisely aligned.[3] The traditional teaching is that watching your hands during ultrasound-guided regional anesthesia is a quality-compromising behavior. However, recent evidence suggests that initial visual guidance can improve the speed of subsequent sonographic guidance for regional anesthesia interventions.[4] Furthermore, in-plane lineups of novices are typically better when the visual axis and needle path are aligned.[5]

NEEDLE REDIRECTION DURING IN-PLANE TECHNIQUE

The traditional teaching is that it is difficult to redirect the needle after it is placed within muscle and that it is necessary to pull it back to the subcutaneous tissue to effectively change the needle trajectory. However, there are some maneuvers that will influence the needle path when the needle is deep within soft tissue. Rotating the needle will change the bevel orientation and have a small effect on the trajectory. Quincke tip needles deflect away from the bevel surface.[6,7] Controlling the amount of transducer compression can alter the needle path, with more compression forcing a slightly steeper approach.[8] In some cases, injecting fluid can create a more favorable needle path if unintended (and displaceable) targets lie in the path.

Hand-on-needle hub provides better needle control for in-plane technique. This is important for blocks above the clavicle where the injection hand is stabilized. Hand-on-syringe provides the ability to control needle movement and injection by a single operator.

Skill is more important than approach alone. There will probably never be a good study comparing the two approaches (out-of-plane versus in-plane) because of strong institutional biases and effort dependence regarding how to perform regional blocks.

By musculoskeletal convention, the long-axis images are shown with the proximal side on the left and the distal side on the right. Long-axis views are useful for demonstrating longitudinal distribution of local anesthetic along the nerve path in one image. However, in clinical practice, it is usually easier to view the nerve in short axis and slide along the nerve path in a proximal-distal fashion to assess the longitudinal distribution.

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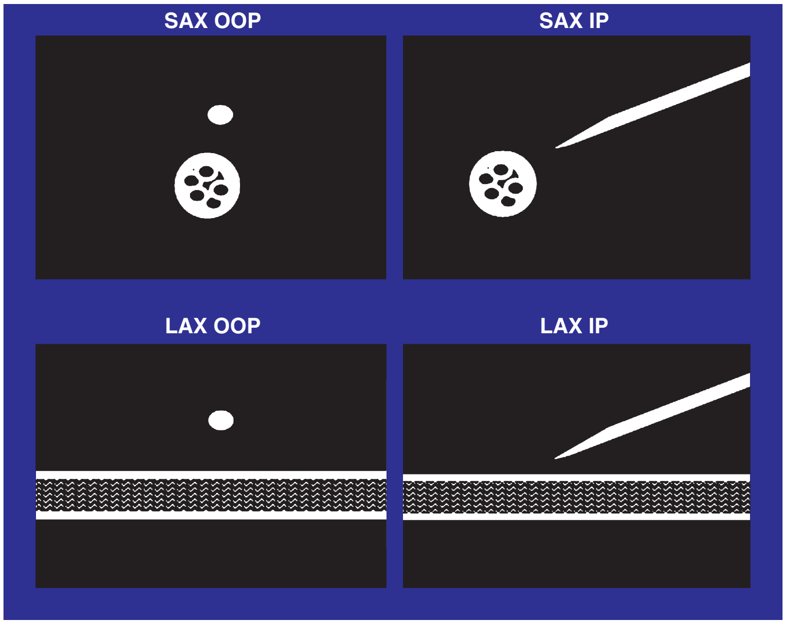

FIGURE 12.1 Schematic drawing of the short-axis (SAX) and long-axis (LAX) out-of-plane (OOP) imaging *(left panels)*, and SAX and LAX in-plane (IP) imaging *(right panels).* (Adapted from Gray AT. Ultrasound-guided regional anesthesia: current state of the art. *Anesthesiology*. 2006;104:368–373.)

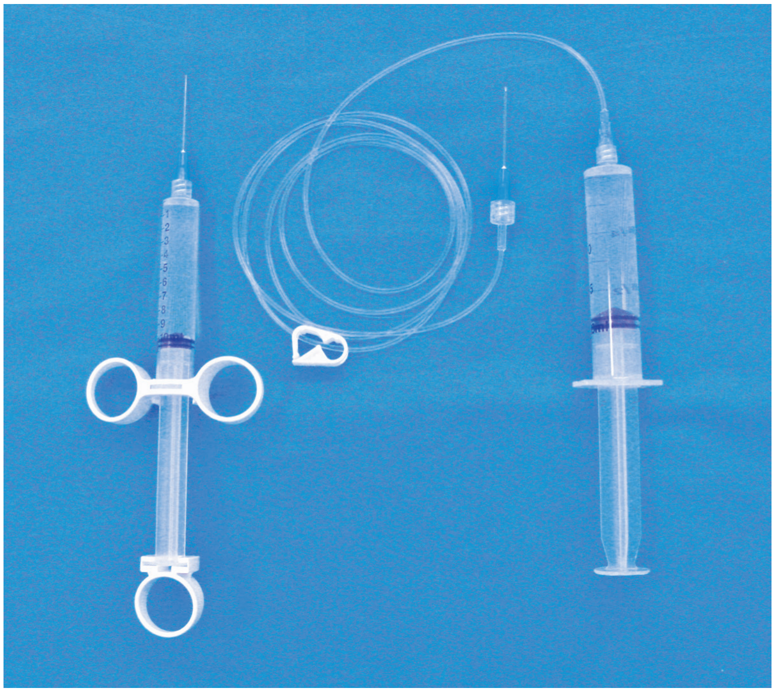

FIGURE 12.2 Setup for regional block with hand-on-syringe or hand-on-needle approaches.

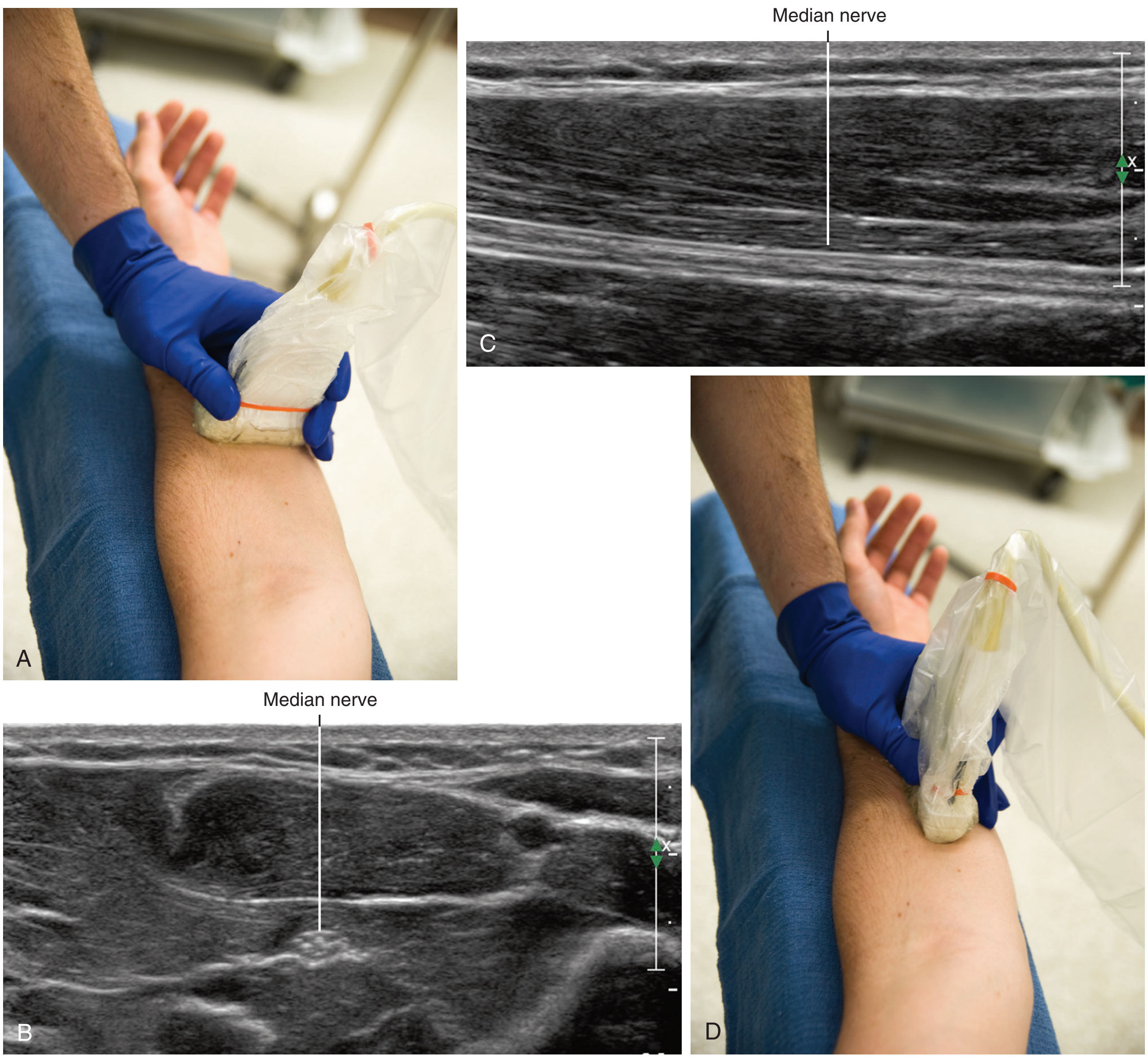

FIGURE 12.3 Median nerve viewed in short axis (A and B) and in long axis (C and D).

CHAPTER 13

Sonographic Signs of Successful Injections

See Video 1.1 on ExpertConsult.com.

It seems simple enough to state that successful drug injections for regional blockade should surround the peripheral nerve. However, studies have reported that the doughnut sign, previously considered the gold standard for success, has a positive predictive value of only 90% for producing surgical anesthesia.[1] It is therefore important to carefully consider multiple factors that constitute sonographic signs for success that can be evaluated after injection.

First, successful drug injections should clarify the nerve border. Most regional blocks are performed with nerves viewed in short axis to evaluate the circumferential distribution. If more than half of the nerve border is contacted by local anesthetic, it is unlikely there is an intervening fascial plane that will serve as a barrier to diffusion. Therefore it is important that the injection round the corner of the nerve so that there is demonstrated curvature of the injection.

Second, successful drug injections will track along the nerve. Although the longitudinal distribution can be imaged with the nerve viewed in long axis, it is usually easier to slide the transducer along the nerve path with the nerve viewed in short axis (short-axis sliding assessment). If the local anesthetic truly tracks along the nerve, it will track along nerve divisions as well. This sign is especially useful for femoral and popliteal blocks because these block procedures are performed near points of nerve branching.

Third, peripheral nerves are often connected to adjacent structures, such as arteries or other peripheral nerves. Because they are covered in common connective tissue, successful injections should separate the connected structures. This is why practitioners often perform infraclavicular blocks or axillary blocks by placing the block needle tip between the axillary artery and the adjacent nerves. Understanding these connective tissue layers can provide a means of keeping the needle tip at a distance from the peripheral nerves.

Fourth, peripheral nerves are often more echogenic after injection of local anesthetic. This is because anechoic fluid has been injected into an attenuating sound field. This is not a perfect sign of success because anechoic fluid introduced anywhere between the nerve and the skin surface can cause this same effect.

Reference

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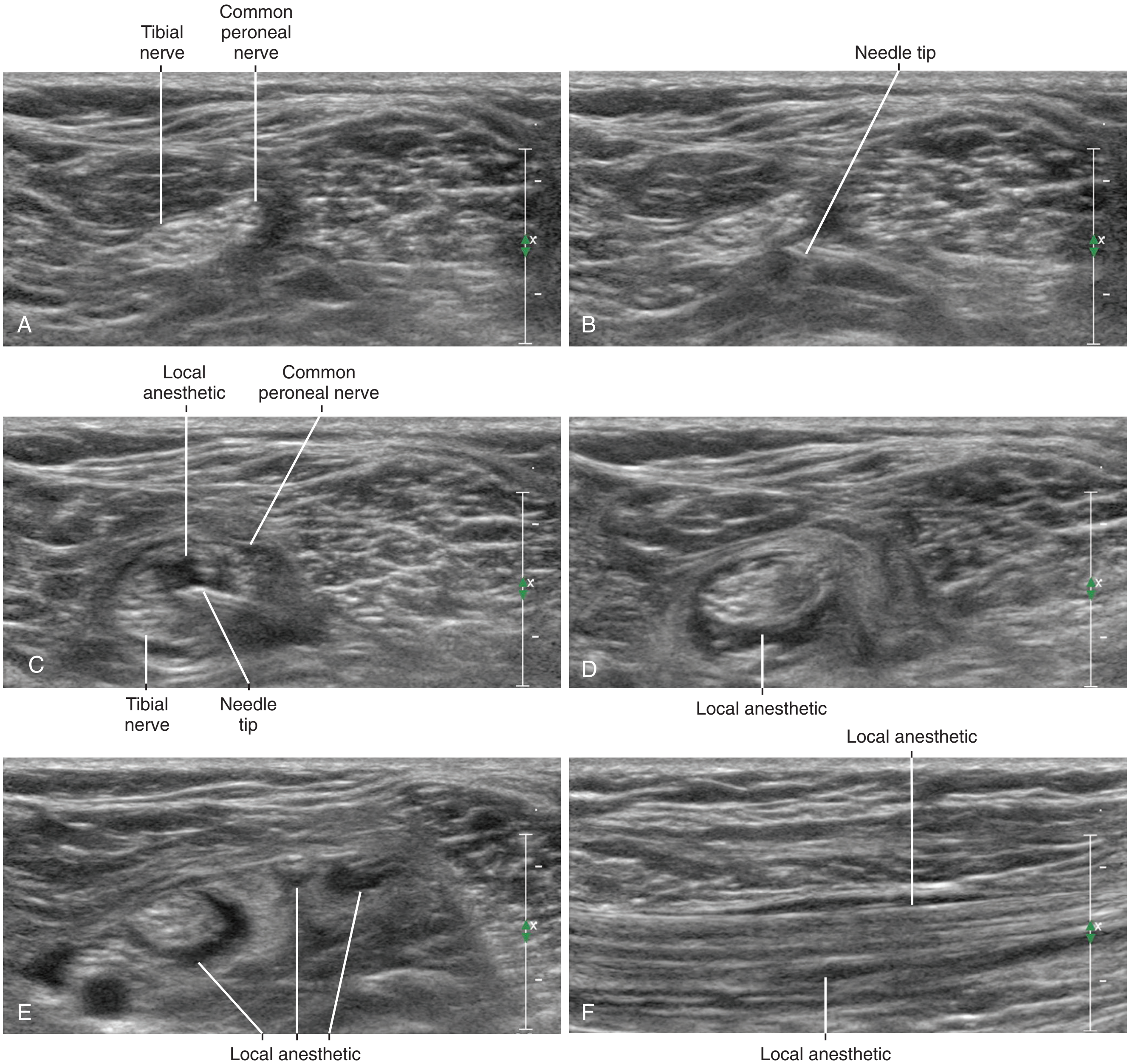

FIGURE 13.1 Image sequence showing successful sciatic nerve block in the popliteal fossa. The tibial and common peroneal contributions of the sciatic nerve are viewed in short axis before injection (A). An in-plane approach is demonstrated where the needle tip is placed between the tibial and common peroneal nerves (B). Local anesthetic is injected between the nerves (C). After injection, local anesthetic is distributed around the nerves (D) and tracks along nerve branches (E). A long-axis view also verifies the local anesthetic distribution along the sciatic nerve (F).

CHAPTER
14

Ultrasound-Guided Continuous Peripheral Nerve Blocks

Daniel A. Nahrwold

See Video 1.1 and Video 14.1 on ExpertConsult.com.

INTRODUCTION

Ultrasound-guided continuous peripheral nerve blocks can be placed with high success rates and low complication profiles in both adults and children.[1,2] Peripheral nerve catheters are more beneficial than traditional opioid-based analgesia and also are associated with improved pain control, lower opioid requirements, less nausea, and greater patient satisfaction when compared with single-shot blocks.[3–5] Catheters are commonly placed at the interscalene, supraclavicular, infraclavicular, sciatic, femoral, adductor canal, and popliteal sites. A short-axis in-plane approach to peripheral nerve catheter insertion is popular, although out-of-plane techniques and long-axis approaches also have been described.[6]

SUGGESTED TECHNIQUE

When placing peripheral nerve catheters, many practitioners use the same short-axis in-plane approach that is commonly used for single-shot blocks.[7] The clinician must demonstrate proper hand hygiene and maintain sterile technique throughout the entire procedure.

After ultrasound imaging of the needle tip in close relation to the nerve has been obtained, the proceduralist typically injects 10 to 20 mL of local anesthetic or saline to create space into which the catheter can be advanced. The catheter is threaded through and then beyond the needle tip, leaving the catheter either alongside or around the peripheral nerve. Catheter advancement is usually accomplished without ultrasound guidance, although advances in ultrasound needle guidance systems can allow for catheter advancement with real-time ultrasound assistance.[8]

The needle is now withdrawn over the catheter. The catheter is then viewed using ultrasound, and tip placement can be confirmed by injecting 1 mL of air through the catheter.[9] Based on ultrasound interrogation, the catheter may be slightly withdrawn to an optimal location in close proximity to the nerve. Additional local anesthetic may now be given through the catheter. The catheter is then secured with a skin adhesive followed by transparent sterile dressing placement.[10]

A long-axis in-plane approach to continuous peripheral nerve blocks has been described.[11] In this approach, the peripheral nerve, needle shaft, and catheter tubing can all be viewed in the same ultrasound image. However, it can be difficult to manipulate the transducer to maintain all three structures within the plane of imaging. One study found that the onset of sensory anesthesia was faster only to be negated by a slower procedure time when using a long-axis in-plane approach to femoral nerve catheter placement.[6] No other advantages were described, and the complication profile was similar to catheters placed with the short-axis in-plane technique. Subgluteal sciatic nerve catheters seem particularly amenable to the long-axis in-plane approach when the patient is placed in the prone position.

DISCUSSION

Placing peripheral nerve catheters with ultrasound guidance alone is faster, causes less procedure-related pain, is more cost effective, and provides equivalent anesthesia when compared with catheters placed with stimulating needles and stimulating catheters both with and without ultrasound guidance.[12–15] When injecting local anesthetic, similar times to sensory and motor anesthesia can be achieved by injecting through the needle or the catheter.[16,17] Catheter-insertion distance past the needle does not appear to affect the quality of analgesia, and many practitioners aim to thread the catheter 1 to 5 cm beyond the needle tip.[18]

A relatively new method for placing peripheral nerve catheters is known as the catheter-over-needle (CON) technique. As its name suggests, the catheter is already loaded onto the block needle, and once the needle/catheter unit is in proper location adjacent to the nerve, the practitioner removes the needle as the catheter remains in place. As compared with the catheter-through-needle (CTN) technique, the CON approach may cause less fluid leakage at the skin insertion site and less catheter dislodgement. Further studies are in progress to evaluate these and other potential differences between the techniques.

Catheter orifice configuration may influence the quality of nerve blockade, with multiorifice catheters providing superior analgesia when compared with end-hole catheters.[19] Finally, complications related to continuous peripheral nerve blocks, such as bleeding, infection, neurologic injury, and local anesthetic toxicity, have been studied and remain relatively low.[1,20]

Clinical Pearls

- A successful peripheral nerve catheter program requires trust and collaboration between the anesthesia team and clinicians from other medical and surgical specialties.
- Customized peripheral nerve catheter kits that bundle high-quality and validated supplies may allow for greater efficiency and better results.
- In the short-axis in-plane approach to continuous peripheral nerve blocks, rotating the bevel of the needle 90 degrees may allow the catheter to be positioned alongside the nerve rather than above or below it. A styletted catheter is often easier to advance past the needle and into the tissue adjacent to the nerve. After injecting local anesthetic or saline through the block needle, withdrawing the needle slightly may allow the catheter to thread with more ease.
- Careful attention to ergonomics can lead to less fatigue and more success when placing peripheral nerve catheters. Keep the ultrasound screen at eye level directly across from where the block is being placed. Hold the ultrasound probe near its end, with the hand braced against the patient's skin. Be conscious of bed and procedure table height. Posture is particularly important, and sitting may aid placement of some continuous blocks, especially popliteal catheters.
- Dilute solutions of local anesthetics can be safely administered through peripheral nerve catheters using commercially available delivery systems both in the hospital and at home. Patient education including succinct written instructions must be provided to patients who will be managing and removing their catheters at home.[4]

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FIGURE 14.1 The equipment necessary for ultrasound-guided peripheral nerve catheter placement.

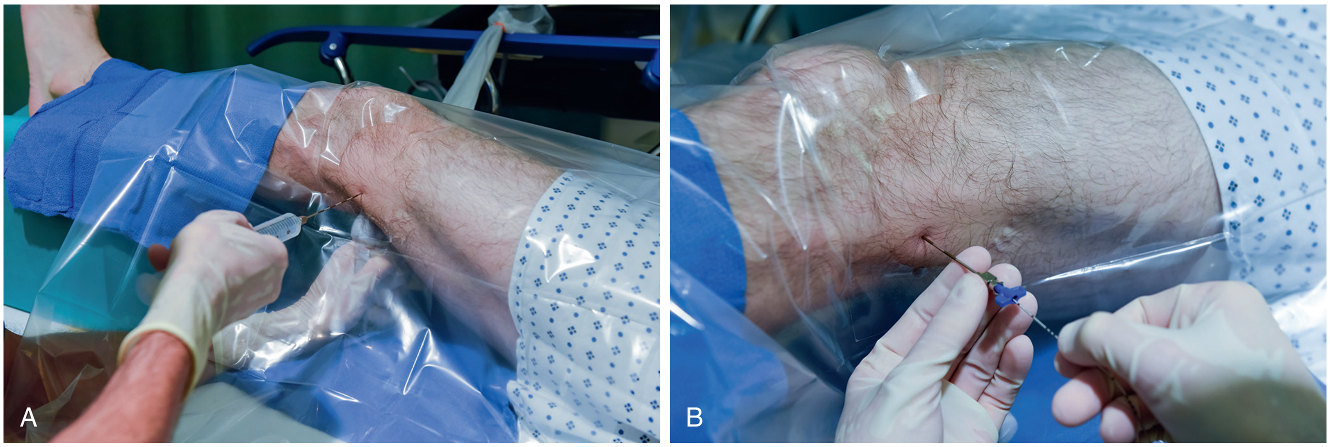

FIGURE 14.2 External photographs showing the approach to popliteal catheter placement. The proceduralist shown connects a 20-mL syringe directly to the Tuohy needle and advances into the popliteal fossa with ultrasound guidance (A). The catheter is then threaded into and past the Tuohy needle (B). Catheter placement is confirmed by sonographic assessment.

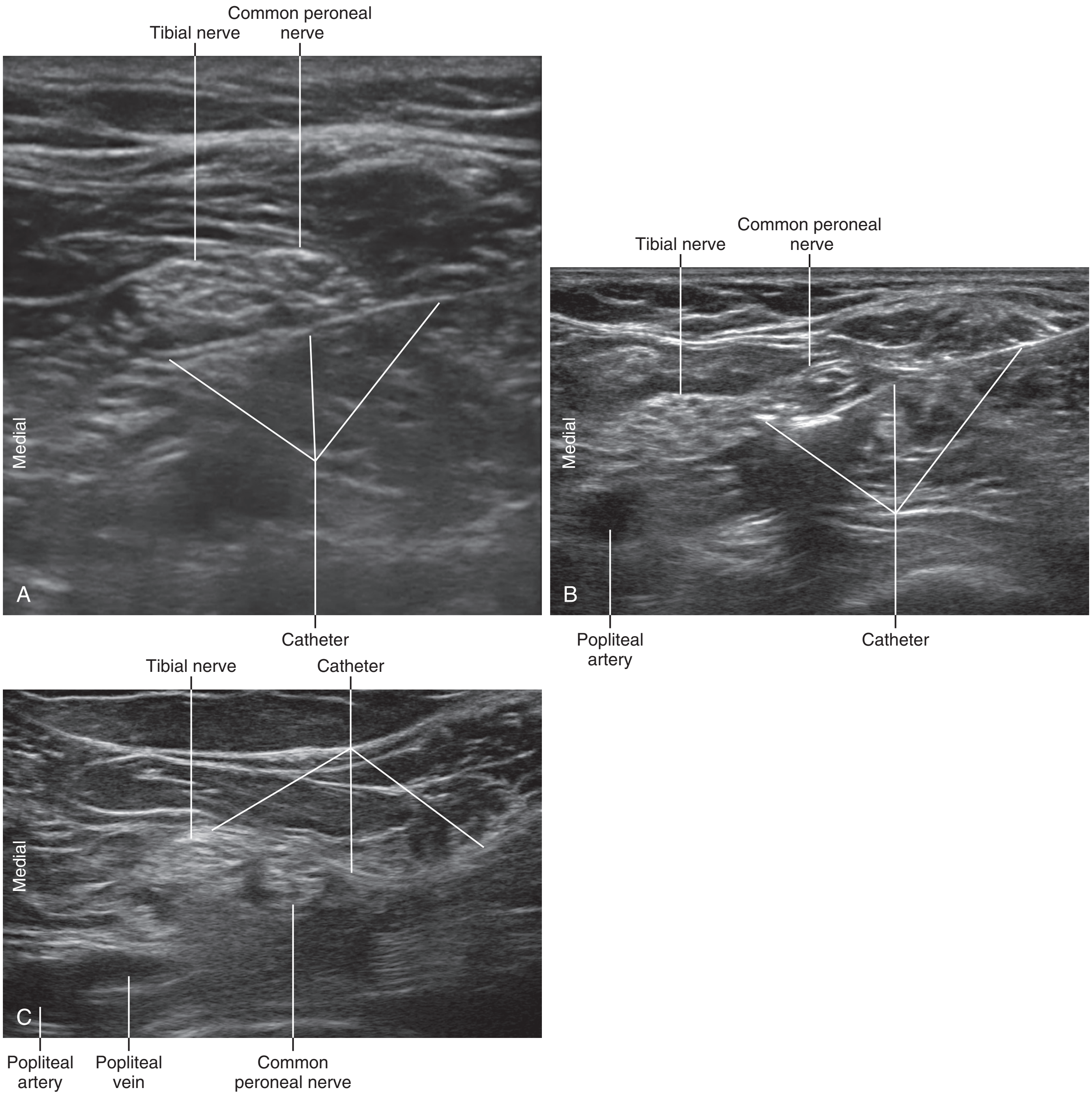

FIGURE 14.3 Ultrasound imaging of a peripheral nerve catheter in the popliteal fossa. The catheter is placed below (A), between (B), or above (C) the common peroneal and tibial branches of the sciatic nerve. All catheters were functional.

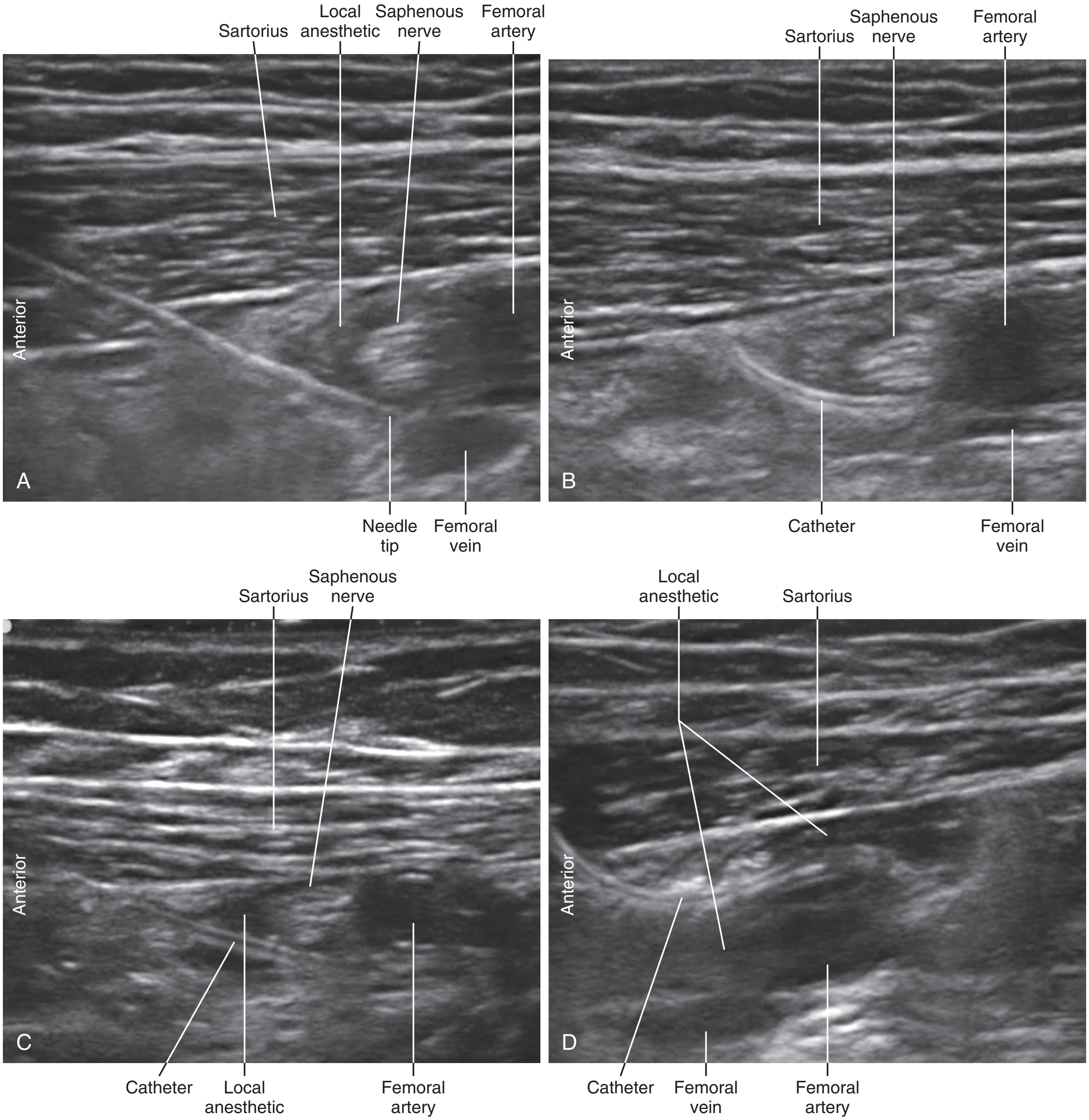

FIGURE 14.4 Sonographic assessment of a peripheral nerve catheter in the adductor canal. The space is dilated with an injection of local anesthetic or saline through the needle (A). The catheter is then advanced and typically tracks adjacent to (B and C) or above (D) the femoral artery.

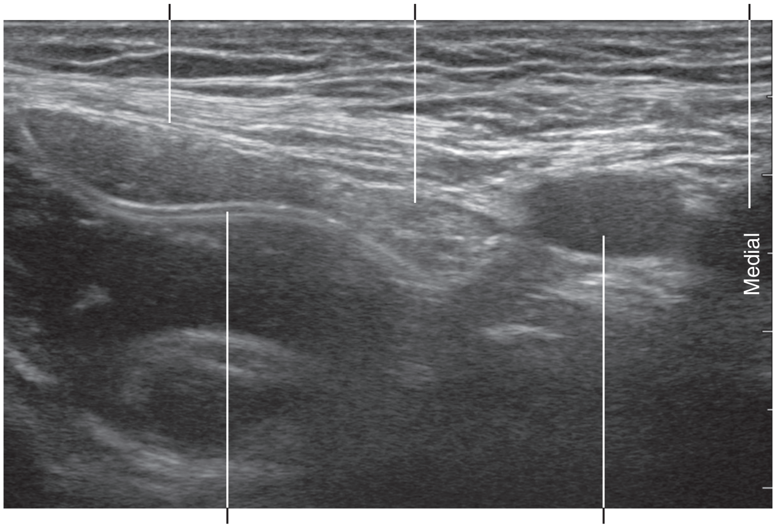

FIGURE 14.5 Advancement of a peripheral nerve catheter for continuous femoral nerve block. Note the triangular appearance of the femoral nerve and the catheter tracking below it.

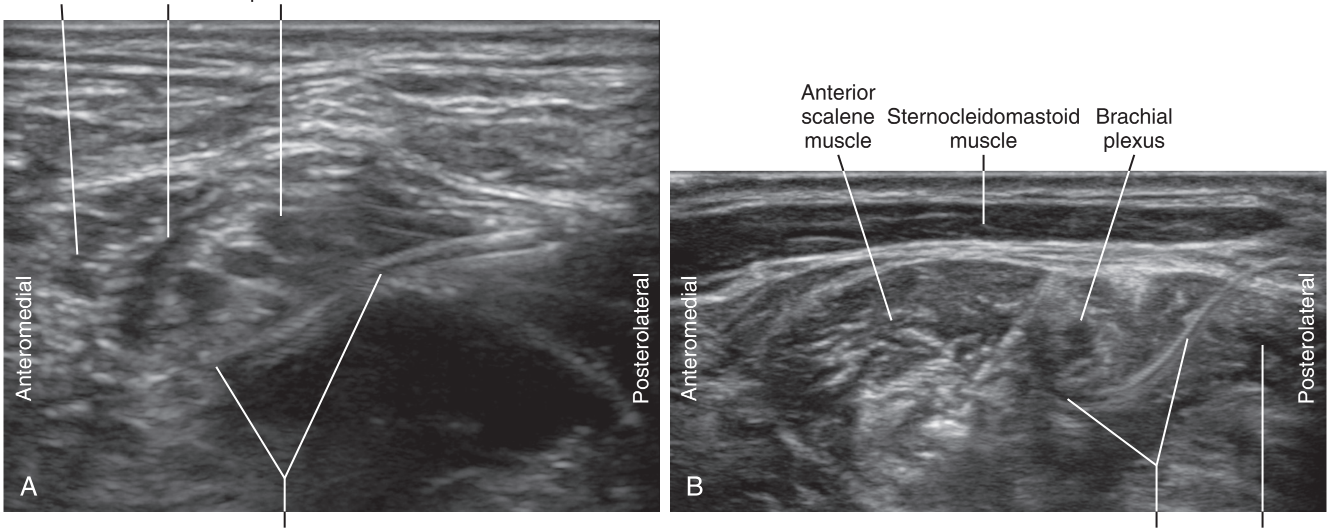

FIGURE 14.6 Ultrasound imaging of a peripheral nerve catheter in the interscalene groove (A and B). If the catheter is placed within the groove, it does not matter on which side of the brachial plexus the catheter is positioned for adequate nerve blockade to occur.

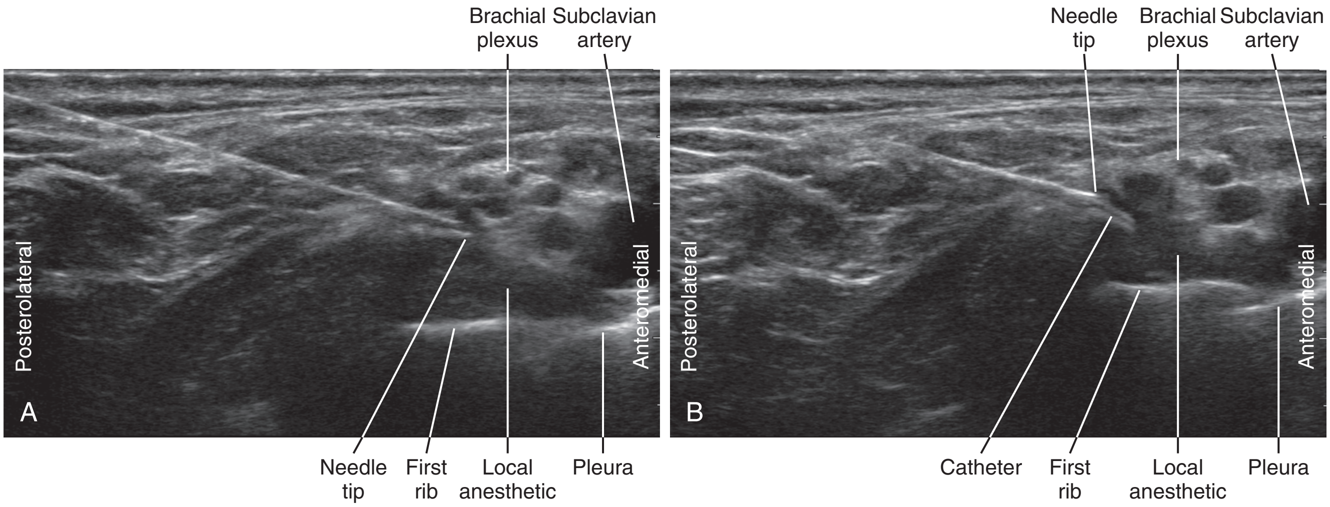

FIGURE 14.7 Image sequence showing continuous supraclavicular nerve block. The needle tip is advanced toward the subclavian artery. Local anesthetic or saline is then injected in close proximity to the divisions of the brachial plexus (A), creating a space for threading the peripheral nerve catheter (B).

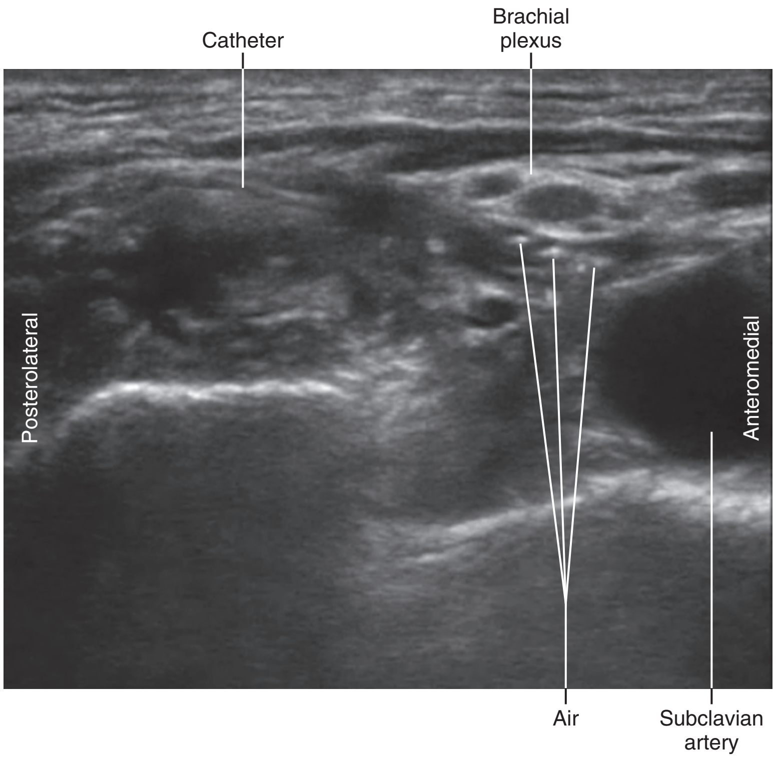

FIGURE 14.8 Sonogram showing an air test to confirm catheter placement for continuous supraclavicular nerve block. Ultrasound imaging of the peripheral nerve catheter often proves difficult to obtain. Injecting 0.5 to 1 mL of air through the catheter can help identify catheter tip location.