Ultrasound Guidance in Anesthesia

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Sonography addresses a variety of concerns, such as patient safety and comfort, cost-effectiveness, time to complete a procedure, and success rates associated with invasive anesthesia procedures. Ultrasound guidance is commonly being used for the placement of nerve blocks, placement of peripheral and central lines, and arterial catheterization. Recently, it has been applied to preprocedural and imaged-guided spinal and epidural placement. The general terms and application of ultrasound to the practice of anesthesia are discussed in this article, as well as the general principles and the interpretation of basic images. Common procedures that include its use are also reviewed.

Keywords: Imaging, sonography, regional anesthesia, ultrasound, vascular access.

Ultrasound guidance in anesthesia is receiving a great deal of attention. Current research suggests that it has many attributes, especially for the application of regional anesthesia procedures. Sonography addresses a variety of concerns, such as patient safety and comfort, cost-effectiveness, time to complete a procedure, and success rates associated with invasive anesthesia procedures. Ultrasound guidance is commonly being used for the placement of nerve blocks, placement of peripheral and central lines, and arterial catheterization. Recently, it has been applied to preprocedural and imaged-guided spinal and epidural placement. It seems that ultrasound has kindled interest into the performance of relatively new peripheral nerve blocks as well. An example of this was presented by Belavy et al[1] regarding placement of the transverse abdominal plane (TAP) block. They reported no complications, a decrease in postoperative nausea and vomiting following cesarean delivery, and a reduction in postoperative analgesic requirements.

Conventional methods can be blended with sonography as well. Early research articles regarding ultrasound and peripheral nerve blocks suggest increased success and decreased complication rates while combining nerve stimulator and image guidance.[2] Anesthesia practices across the globe are producing research that suggests ultrasound-guided procedures are becoming safer, faster, and cheaper; provide greater patient comfort; and are more effective than traditional methods.

Sonography is allowing new procedures to be accomplished as well as improving existing ones. For example, Horn and associates[3] reported a novel approach to saphenous nerve block under ultrasound guidance. The *Canadian Journal of Anesthesia* stated that ultrasound guidance improves the readiness for surgery and shortens the time required to perform infraclavicular blocks vs nerve stimulator.[4] Tedore et al[5] reported that compared with the transarterial approach, the ultrasound-guided infraclavicular block was associated with greater patient comfort and increased willingness to undergo future blocks. Other authors suggested that ultrasound can decrease but not eliminate complications such as intraneural injection during brachial plexus blockade.[6] Use of sonography has also been associated with a reduction of local anesthetic during regional block placement.[7] This may have a positive impact on the attitudes about regional technique safety, especially in children.

Evolution of Ultrasound

The first article on the medical application of ultrasound was by Dr. Karl Dussik, an Austrian psychiatrist. He is reported to have termed the images *hyperphonography*.[8] The traditional single probe technique was not used, rather an emitter probe was applied to 1 side of the head and the receiver was positioned opposite it. The application was designed to image the brain for tumors.[8] Scottish physician, Ian Donald, is reported to have applied the first traditional single probe application of ultrasound in 1957.[9] One year later, ultrasonography was used for pregnancy imaging. LaGrange et al[8] first suggested that ultrasound be used for anesthesia applications such as peripheral nerve blocks as early as 1978. It has become a useful tool for a variety of applications recently because of the production of cost-effective technology and decisions to incorporate selective applications into practice.[10] This article will present basics relative to ultrasound beams and scanning techniques. It will also discuss the variety of anesthesia applications that can employ its use.

Ultrasonic Waves

The term *ultrasound* refers to the use of sound waves from 2 to 15 MHz. Our ears can interpret sound waves in the 20 to 20,000 Hz range; thus, ultrasound cannot be heard by humans. All sound waves, including ultrasound, can be described by 7 characteristics. These are period, frequency, propagation speed, amplitude, power, intensity, and wavelength. To enhance the image, the provider can manipulate some of these sound wave

Wave characteristic	Definition	Changeable
Period	Time it takes to complete 1 cycle	No
Frequency	Number of cycles per second	No
Propagation speed or acoustic velocity	Speed that a sound wave moves through something	No
Amplitude	Magnitude of the wave	Yes
Power	Strength of the wave	Yes
Intensity	Concentration of energy in a sound beam	Yes
Wavelength	Distance that 1 cycle of sound occupies	No

Table 1. Definitions of Sound Wave Characteristics

properties.[11] Table 1 lists these terms and their definitions.

The ultrasound waves are emitted by a probe and passed though tissue. Different structures reflect or absorb these waves.[11] The term *absorption* is used to describe ultrasonic wave loss. This loss occurs as the waves are applied to tissue and converted into a different form of energy, such as vibration or heat. Reflected waves are then received back to the probe. The returned data are reproduced as an image on a monitor. The image then can be used to make a variety of measurements, such as the size or depth of a structure, presence of arterial or venous flow (Doppler application), location of a nerve, or to detect structural anomalies. This imaging can be very valuable in a various settings that include the invasive procedures of modern anesthesia practice.[11]

Probe Selection

The term *probe* is another name for transducer. Edelman[11] explains that a transducer's purpose is to convert one form of energy into another. In the case of ultrasound waves, this means to convert electrical energy into acoustic energy. To accomplish this, the probe uses piezoelectric material. There are several different materials that exhibit this characteristic. The man-made materials are lead zirconate titanate (PZT), lead titanate, lead metaniobate, and barium titanate. The substances found in nature are quartz, (commonly found in timepieces), Rochelle salts, and tourmaline. When electrical current is applied to a piezoelectric material, a shape change occurs and causes it to vibrate. These vibrations emit ultrasonic sound waves. This is known as the piezoelectric effect. The piezoelectric crystal is the functional unit in most diagnostic ultrasound imaging. It is important to remember that elevated temperatures applied to a piezoelectric material will cause it to become permanently depolarized. This will impair the material's ability to change shape and produce ultrasonic waves.

There are 2 types of commonly used ultrasound probes: the linear or flat probe and the curved, or curvilinear, probe. These 2 probes share a few common characteristics. Both probes use PZT as the material that actually produces the ultrasonic beam. On the proximal portion of the probe there is a dampening material, used to limit ringing of the PZT crystal. This is commonly made from a resin and tungsten composite.[11] Selection of the proper probe depends on a few factors. The depth of the target structure is probably the most important criterion. As structures get farther away from the probe surface, the ability of the sound waves to be reflected back diminishes. A curved probe has the advantage of producing readable images at great depth, but peripheral images lose some resolution. The outer edges of the sound waves are not returned in the same amount as they are produced. Hence, the edges of the image may not produce a sharp or even readable picture. Conversely, the flat probe can produce a larger, sharper image for more superficial structures but loses resolution at depth more easily then does the curved probe.[11]

Ultrasound Image Terms

Standard terms allow providers to communicate effectively pertaining to interpretation of ultrasound images. Common ultrasound terms include *penetration, resolution, echogenicity, artifact, shadow*, and *distortion*. Table 2 summarizes the definitions of these terms.

There are 2 types of resolution: longitudinal and lateral. Longitudinal resolution refers to the ability to distinguish 2 or more separate objects that are superficial or deep to one another. Lateral resolution refers to the ability to distinguish 2 or more objects that are located next to each other, but at similar depth. These concepts of penetration and resolution are thought to be inversely related. For example, deeper structures require greater penetration to obtain images. This produces poor images, hence, poor resolution. Echogenicity refers to the structure's ability to absorb or reflect ultrasound waves.[11] Dense structures, such as a needle or bone, reflect more and are usually imaged as white or "hyperechoic." Liquid or air-filled spaces are generally considered "hypoechoic," as they reflect fewer waves and are imaged as black. For example a needle is generally seen

Term	Definition
Penetration	Degree of transmission of ultrasound through tissue; commonly measures depth, usually in centimeters
Resolution	Ultrasound machine's ability to produce quality images
Echogenicity	A structure's ability to absorb or reflect ultrasound waves
Artifact	Any error in imaging
Shadow	Created by a beam's high degree of reflection from the surface of a dense structure
Distortion	Image of tissue as it twists and bends during manipulation

Table 2. Definitions of Common Ultrasound Terms

as a hyperechoic dot when viewed in cross section.[12]

There are several types of artifact that can create a repeating mirror image, undesired brightness, or speckling of the image. This is commonly caused by an insufficient amount of conductive medium such as gel.[11] A shadow is created by a beam's high degree of reflection from the surface of a dense structure. The surrounding beam continues to penetrate properly; however, the space below the density is shrouded in darkness. The ultrasound beam is therefore unable to produce images beyond the superficial edge of a shadow. Distortion may be the result of imaging the movement of tissue, by a needle, which is not in the beam plane.

Scanning Techniques

Ultrasound in the practice of anesthesia is used primarily for imaging structures relative to needle placement. Structures can be visualized in a cross section or longitudinal section. The 2 techniques used to image the needle's location are in-plane and out-of-plane technique.[12] The out-of-plane technique allows visualization of the needle as a dot crossing the ultrasound beam. This technique is popular for vascular access, as it produces an image of the vessel in cross section. This also allows for angle variation, because imaging is not intended to see the length of the needle. The out-of-plane technique is accomplished by first obtaining an image, then introducing the needle under the beam plane in the middle of the wide portion of the probe. It is useful to place the target in the middle of the screen.

The in-plane technique produces an image of the entire needle, most importantly the tip, as it is directed to a particular structure. This is done by first obtaining an image and then placing the needle under the narrow or side portion of the probe. It should be noted that the ultrasound beam is very thin. If the needle travels outside the beam, it will not be seen. A probe with a needle guide will assist with the in-plane technique; however, needle guides are not often used. The in-plane technique allows the performance of regional blocks with greater safety and helps reduce the incidence of accidental vascular puncture or nerve contact.[12]

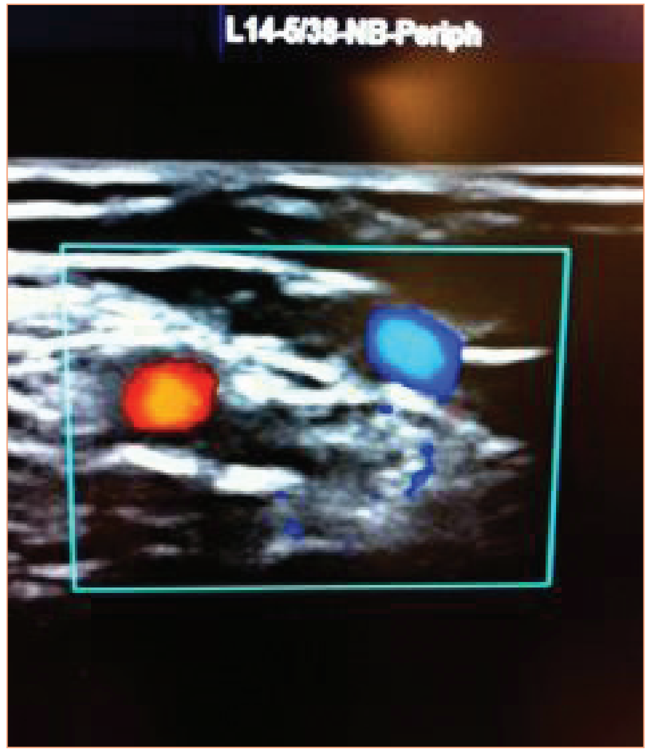

Figure 1. Color Doppler Image of the Brachial Artery and Vein

Doppler Mode

The Doppler will produce a dynamic, pulsatile flashing that can be differentiated from the low velocity form of venous flow. Doppler flow is interpreted by measuring the velocities of moving blood cells. Flow toward the transducer produces higher frequencies with shorter wavelengths, while flow away from the probe elicits lower frequencies with longer waves. The difference in these sent and received waves is known as the Doppler shift. The shift is either positive or negative. This is then superimposed as color onto a gray, 2-dimensional (2D) image, to produce a dynamic picture. A Doppler mode can assist in distinguishing arteries from veins. The flow of blood is usually denoted by red and blue. Red generally indicates high velocity flow toward the transducer, and blue indicates low velocity flow away from it. Currently, there is no industry standard for this indication, and this may vary from unit to unit (Figure 1).[11]

Aspects of Clinical Use

Three steps are involved in the practical aspects of ultrasound use in clinical anesthesia: (1) image acquisition, (2) image interpretation, and (3) needle placement. Image acquisition is the clinician's ability to produce a

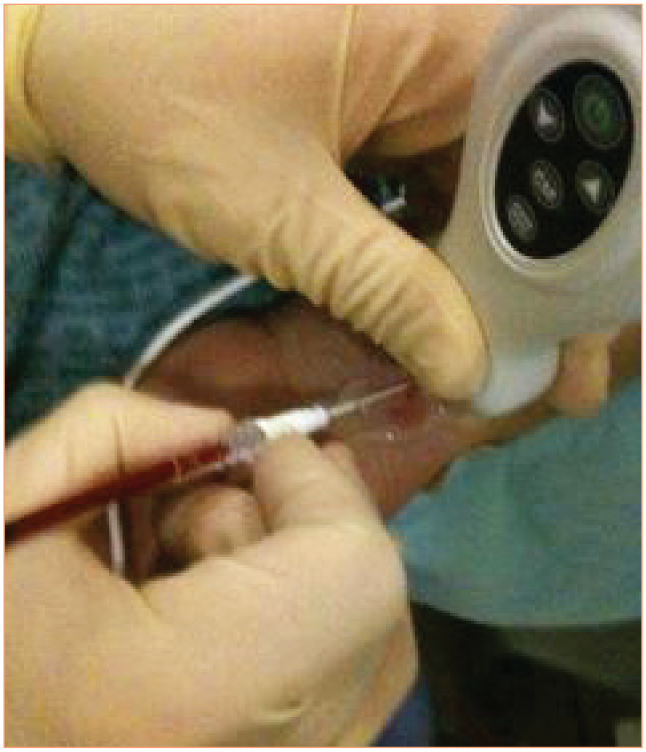

Figure 2. Proper Placement of Ultrasound Probe for Arterial Cannulation

Figure 3. Ultrasound Image of Radial Artery
Note the dark (hypoechoic), oval shaped structure near the top of the ultrasound image (arrow). This represents the artery in an out-of-plane (short axis) orientation.

usable image. There are a variety of ultrasound machines, each with a multitude of different features. Some of the favorable features include having a variety of probes for imaging, Doppler capabilities, manual adjustments for brightness and contrast, and caliper functions. Having familiarity with the machine's functions facilitates a brisk procedure and reduces patient discomfort. This familiarity will also inspire confidence in the clinician performing the procedure and can aid in producing a clear image under adverse or nonideal situations.

The ability to interpret an image is the second step of using ultrasound. It combines anatomy with the ability to predict how the structures will likely appear on the monitor. A common mistake that a beginning practitioner makes is scanning structures on the monitor prior to placing the probe in a proper anatomic position. Once the probe is correctly positioned, the image can be interpreted more easily. One technique to improve image interpretation is to derive the smaller target structures from larger, more easily identifiable structures around it. For example, a clinician may find it difficult to accurately identify the femoral nerve simply by predicting its location and attempting to image it. However, it may be easier to first image the femoral artery and then move the probe laterally to see the nerve.

The last skill to develop in incorporating ultrasound into practice is performing procedures while maintaining and interpreting the image. Bloc and associates[13] reported that skills to perform blocks are acquired over time. Their research suggests that a provider must perform approximately 20 ultrasound-guided axillary blocks before being able to confidently complete the block in less than 5 minutes. One useful technique in maintaining an image is to steady the probe hand by resting it on the patient. This will prevent arm and hand fatigue. It is also advisable to rest the hand moving the needle on the patient as well. This will prevent accidental puncture if the patient moves inadvertently. It is of great importance to master the skill of controlling the probe while advancing the needle forward. This ensures that the tip is always visible on the in-plane view. It is important to remember that changes in beam angles as little as 10° can affect the image. Additional resources for ultrasound application, such as having another skilled person available to guide in the process, are essential to the improvement of technique. The premise of future widespread utilization of ultrasonography in anesthesia practice will likely promote its use during training programs.

Imaging for Arterial Access

The use of ultrasound for arterial cannulation has been associated with fewer attempts and increased success rate.[14] Arterial imaging may be the easiest to perform. Arteries are reproduced on the monitor as dark, hypoechoic, round densities. Even in low flow states, they reliably produce the characteristic pulsing motion. This is distinguished from the nearby vein, as the artery is nearly perfectly round and relatively noncompressible. The artery can be viewed easily in cross section for an out-of-plane cannulation. The needle tip will produce a hyperechoic dot that can be manipulated until it is positioned inside the pulsing black circle. The in-plane image can also be used, as it will produce a dark, thick ribbon crossing the screen, denoting the artery in longitudinal section. Placing a caliper at the artery's superficial surface, in either view, will determine the vessel's depth.[15] When the needle reaches the lumen on the screen, it will produce the characteristic bright-red flash in the cannula. Upon confirmation of luminal breach, the imaging should cease and the task of cannulation should be completed. Figure 2 and Figure 3 depict proper probe placement and image of the radial artery.

Imaging for Central Line Placement

Ultrasound guidance has been recently associated with a reduction in complication rates and an increase in success rates.[16] It has also been suggested that its use during central line placement allows for a reduction in time-to-procedure completion.[16] The American College of Surgeons released a practice statement in 2008 advocating the use of ultrasound guidance for the placement of central lines for patients undergoing elective cardiac surgery.[17] The following steps can be manipulated according to provider preference, keeping in mind that the result must include a sterile field. An image of the site of cannulation can be obtained prior to an attempt, or during the procedure, for guidance. The probe must be placed in a sterile sleeve with conduction gel inside the sleeve as well as on the skin. The same process for arterial cannulation is repeated, except the practitioner targets the large compressible vein instead of the artery. In the Trendelenburg position, the internal jugular vein can be viewed as it engorges, yet is easily compressed. Viewing this image illustrates why the internal jugular vein can be difficult to cannulate if the proper position is not obtained. The vein will simply collapse against the pressure of carotid palpation, protection of the artery by the provider's fingers, or firm slow intrusion of the needle. Upon withdrawal of venous blood, the imaging should cease, and attention paid to completion of the procedure.[18] Figure 4 illustrates proper probe placement, and Figure 5 shows a sonogram of the carotid artery and internal jugular vein.

Imaging for Spinal and Epidural Placement

Ultrasound has recently become a useful tool to assist in spinal and epidural placement. Imaging the spine prior to needle placement has a few advantages over the traditional surface landmark or blind approach. The first advantage is the ability to accurately determine the distance to either the ligamentum flavum or subarachnoid space. This information can be useful in the prevention of unintentional dural punctures during epidural placement, especially in the parturient.[19] This is especially useful in neonates and children, as these distances may vary greatly with size and age.[20]

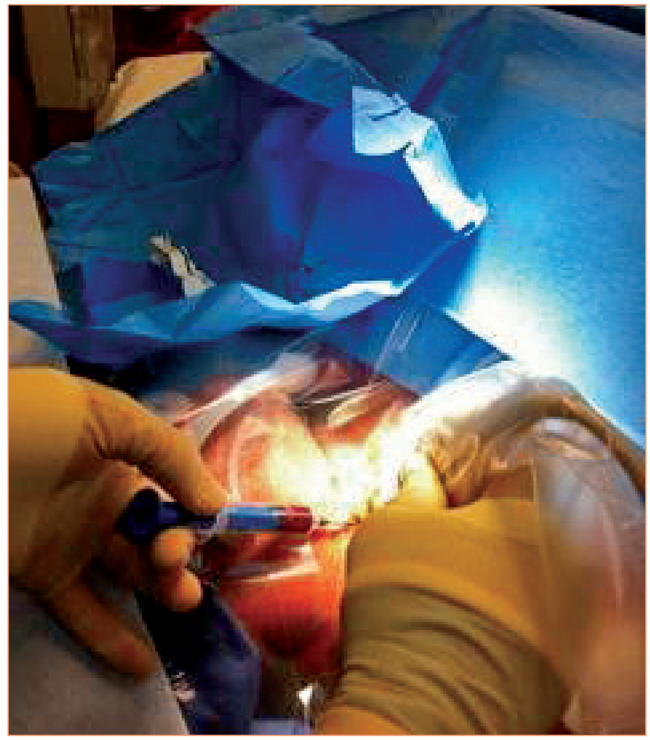

Figure 4. Proper Probe Placement for Central Line Placement

Ultrasound imaging of the spinal structures also has value for the patient who presents for neuraxial anesthesia having had prior spine surgery or is morbidly obese.[21] There are 2 techniques to assist providers with ultrasonic guidance relating to neuraxial needle placement. The first is known as templating. This term describes the use of images to predetermine marks on the surface for later needle placement. Measurements of target depth and surrounding soft and bony structures are recorded on the skin, but the probe is not used to visualize needle entry. It is important to emphasize that most insurance carriers will not reimburse for templating, because it does not include real-time ultrasonic needle guidance. However, avoidance of an unintentional dural puncture and sequela in the patient with poor surface landmarks is of great value.[18]

The second technique is real-time imaging for needle placement. This technique uses the probe to maintain a view of the needle as it travels to its target. An interesting challenge of this technique is maintaining the image while employing the traditional loss-of-resistance method. Three tasks are required to be completed simul-

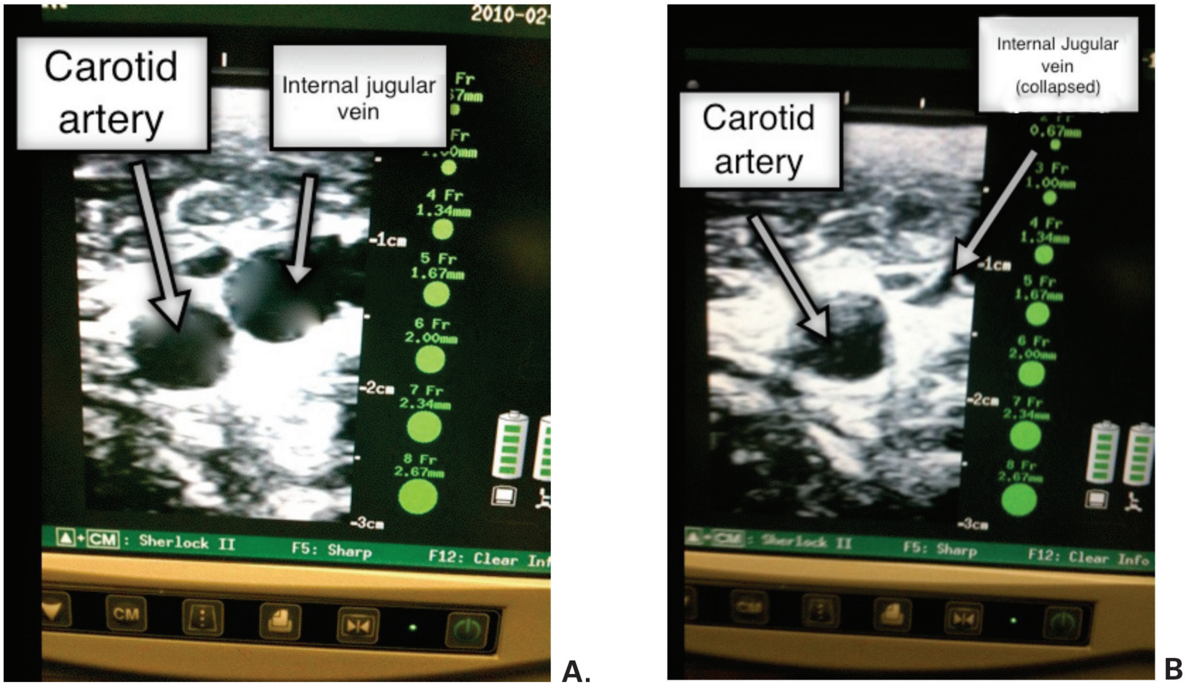

Figure 5. Ultrasound Images of Carotid Artery, Internal Jugular Vein, and Collapsed Jugular Vein
In A, note the large, hypoechoic teardrop shape in the 3 o'clock position (small arrow). This is the internal jugular vein. In B, the internal jugular vein is partially collapsed.

taneously: maintenance and stability of the image, needle advancement, and application of loss-of-resistance technique. In essence, the ultrasound-guided epidural placement is a 2-person endeavor (Figure 6).

Imaging for Regional Blocks

Ultrasound-guided regional blocks can be thought of in 2 categories: perivascular and circumneural. The perivascular technique has gained popularity with many providers, as the goal of the injection is to infiltrate around a vessel known to have nerves in close proximity to it. This image is considerably easier to obtain and interpret, as well as to complete injections, compared with the circumneural technique. As discussed earlier, arteries are distinguished from any other structure because of their large pulsating size and characteristic dark round appearance.[22] Popular sites for this technique are the axillary or subclavian arteries for upper extremity blocks.

The circumneural technique is equally effective but requires the provider to image the nerve itself. Nerve tissue usually appears white in the ultrasound image, but it can change to black as the beam varies from a perpendicular angle. Nerves can be difficult to differentiate depending on the composition of surrounding tissue and the quality of the image. For example, well-insulated nerves surrounded by copious adipose tissue share ultrasonic similarities and, therefore, can be difficult to distinguish one from another. However, if the image quality is good, this technique is equal to the perivascular technique in ease of use and efficacy. Both techniques require the provider to image the needle tip, in relation to the target structure, to rule out contacting it.[22]

Perivascular vs Circumneural Injections

Effective administration of any regional anesthetic necessitates prior study of anatomy. Ultrasound-guided blocks are no exception. Proper interpretation of the image is important to prevent injury and to place the local anesthetic correctly. Imaging for any regional anesthetic should be methodical, beginning with large, easily identifiable structures and progressing to smaller target areas.[22] One example of a circumneural technique would be the interscalene approach to a brachial plexus block. One can begin by first imaging the carotid artery. This can provide an easily identifiable landmark for the posterior location of the brachial plexus. The next structures that can be identified, as the probe is positioned posteriorly, are the large sternocleidomastoid followed by the smaller anterior and middle scalene muscles. These muscles are recognized by their oval and marbled appearance. Deep to the anterior and middle scalene muscles, the trunks of the plexus can be viewed as 3 bright white or, more commonly, 3 dark circles with the characteristic "starry night" appearances within them. This describes the dark circular nerve with dull hyperechoic dots in it. These dots represent the nerve fascicles. An excellent image may even allow the provider to view slight pulsations of the vessel-rich nerves.

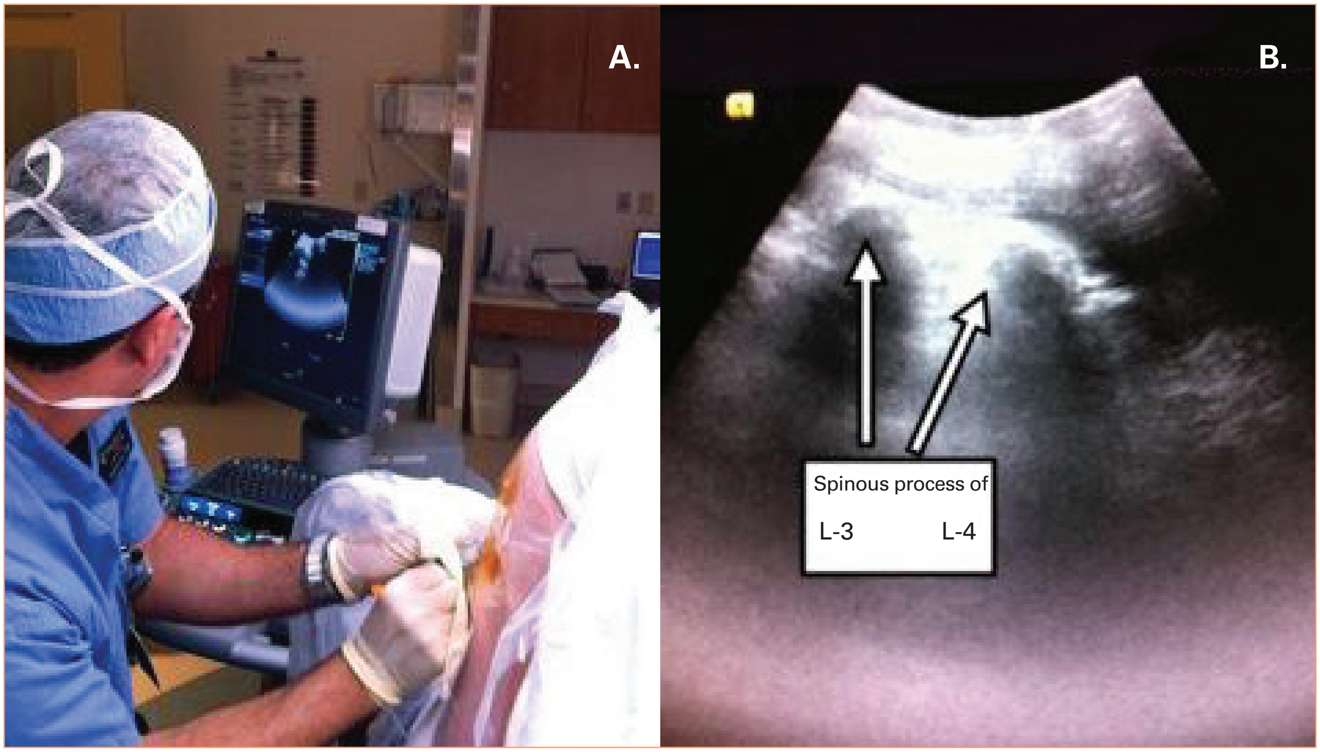

Figure 6. Imaging for Spinal and Epidural Placement
A, curved probe placement for imaging during neuraxial anesthetic placement; B, ultrasound image of lumbar spinous process is shown.

After proper cleansing of the area, the provider should obtain the desired view of the 3 dark "starry night" dots. The in-plane technique is preferred because it is desirable to see the tip of the needle in relation to the structure to be surrounded with local anesthetic. The practitioner should aim the needle toward the side of, not directly at, the nerve. This technique will minimize accidental contact with the structure and allow easier maneuvering deep to it. After negative aspiration, the provider begins to administer local anesthetic, allowing it to diffuse circumferentially around the entire structure if possible.[23] It is critical to observe the spread of local anesthetic, especially the first few milliliters. If the injectate is not observed expanding in the desired space, it is possible that it could be in a vessel. Some clinicians prefer to check the image with a nerve stimulator to confirm the nerve's identity. Infiltrate the deepest structures first, because microbubbles in the injectate will obscure the view after administration. The clinician should observe the spread around the nerve circumferentially and be sure to document that. It is desirable to capture an image of proper local anesthetic spread, without needle contact of the nerve, for medical-legal requirements, as well as billing purposes.

One example of a perivascular technique would be the image-guided infraclavicular block (Figure 7 and Figure 8). The clinician begins by obtaining an image of the large subclavian artery in cross section. This can be found by placing the probe inferior to the clavicle. A desirable site lies about two-thirds of the total clavicular length away from the sternum. The provider then aims the needle behind the artery for deposition of local anesthetic posteriorly. This will ensure radial nerve block and keep the image free from the alterations caused by bubbles in the solution. The technique of hydrodissection can be used to separate the artery from surrounding tissue. This term denotes infiltrating small amounts of local anesthetic or saline for the purpose of separating structures, and ensuring that the proper areas receive the agent. The clinician should continue this process of depositing local anesthetic circumferentially around the artery to include the radial, median, and ulnar nerves.

The use of sonography is advantageous because it allows the provider to image the rib and lung to prevent accidental pneumothorax. It is desirable to image the individual nerves themselves with any ultrasound-guided regional technique. However, the perivascular technique can be used when the individual nerves surrounding the subclavian artery cannot be identified. Since their anatomic location is in close proximity to the artery, it is not necessary to do so. This illustrates the primary difference between circumneural and perivascular techniques.

Ultrasound imaging can also decrease the chance of block failure resulting from improper local anesthetic placement. During nerve stimulation techniques, a proper twitch can be observed at low output, but block failure can still occur because of protection of the nerve by a sheath or other structure.[23] This can be avoided with

Figure 7. Flat (Linear) Probe Placement During Infraclavicular Block

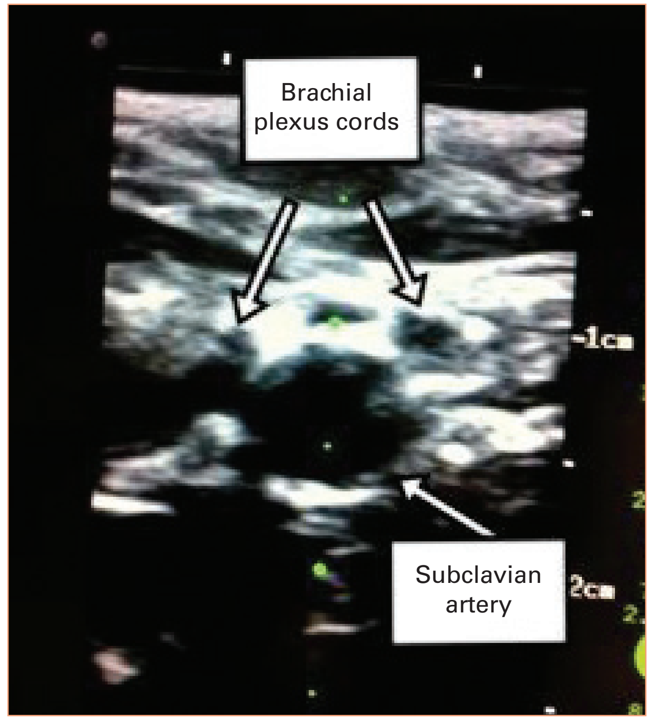

Figure 8. Image of the Brachial Plexus Cords Around the Subclavian Artery in the Infraclavicular Region
The subclavian artery (round hypoechoic circle in the center) is shown with 3 cords (hypoechoic) visible atop the artery. The subclavian vein is seen slightly compressed to the left of the artery.

ultrasound guidance because the provider can observe the contact of local anesthetic with the nerve. Ultrasound techniques can be done with nerve stimulation simultaneously to ensure that the correct nerve is being anesthetized, or to allow the provider to emphasize anesthesia to 1 particular nerve. Another advantage of ultrasound guidance is a theoretical decrease in the incidence of inadvertent vascular puncture because the needle tip is viewed during the procedure.

Conclusion

For nearly 6 decades ultrasonography has contributed to clinical medicine. It is gaining popularity in the practice of anesthesia through its unique ability to noninvasively image structures. Current research demonstrates that ultrasound use addresses issues of patient safety and comfort, reliability, and cost as well as shortens performance time on common procedures. Vessel cannulations, templating and guided images for neuraxial procedures, and nerve imaging are its most common uses, but the future may hold new opportunities for its many abilities. Recently, a group has applied abdominal ultrasound for the diagnosis of a full stomach prior to the induction of general anesthesia.[24] The implications of this may have a tremendous impact on decreasing the incidence of aspiration and its deleterious effects. Ultrasound has great potential for a positive impact on the practice of anesthesia.

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