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Ultrasound-Guided Regional Anesthesia

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Ultrasound Objectives:

There are essentially 4 primary objectives of the anesthesiologist conducting an ultrasound-guided nerve block.

1. Unequivocally image the nerve or plexus.
2. Identify collateral structures such as arteries or pleura.
3. Visualize the needle tip as it approaches the target and avoid collateral structures.
4. Confirm effective perineural spread of local anesthetic.

The ability to accomplish these tasks depends significantly upon the operator's understanding and interaction with the ultrasound machine.

Background Terminology:

Ultrasound is defined as sound waves that are at a frequency of 20,000 cycles per second or Hertz (Hz) or higher. Most transducers used for UGRA are between 4 and 13 million Hz or 4 to 13 megahertz (MHz).

An ultrasound wave is produced when an electrical signal is placed across piezoelectric crystals that force the crystals to vibrate. This vibration is then conducted through the body. All ultrasound waves are characterized by a specific wavelength and frequency. The relationship between these variables is c is proportional to $(\lambda)*(f)$, where c = the propagation velocity and is presumed to be 1540 m/sec in the human body. Therefore, if c is held constant, then to increase the frequency of an ultrasound wave, the wavelength would have to proportionately decrease. This concept is at the core of UGRA since different frequency probes are used for different blocks.

Two additional and important concepts are ultrasound resolution and attenuation. Attenuation is the loss of ultrasound wave energy as it travels through tissue. Generally, a lower frequency wave will attenuate less at a given distance in comparison to a higher frequency wave. Thus, the lower frequency ultrasound wave will penetrate deeper into the patient. Axial resolution, or the ability to identify two or more points in space (one lying in front of the other), is between one to two wavelengths. This means that the lower frequency (larger wavelength) ultrasound beam will penetrate deeper but will lack the resolution of the higher frequency and smaller wavelength beam.

Imagine (not image) if all structures reflected ultrasound to the same degree!

This is very interesting theoretical discussion. When ultrasound travels into the body and reflects off of an object, some of the energy will return to the transducer. When this mechanical energy strikes the transducer, the piezoelectric crystals vibrate again. This time, however, they convert mechanical energy back into electrical energy. By convention, the more of this mechanical energy converted, the whiter or more echogenic the structure will appear. Therefore, the physician identifies structures and pathological conditions by identifying various sine quo non-shades of grey! If all structures reflected ultrasound to the same degree, all structures would appear the same shade of grey and we would not have any useful clinical information. It would be like going to the opera and hearing only one tone for 2 hours. No fun.

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To be more scientific, 'targets' for UGRA are generated based on the concepts of reflection and impedance. Impedance can be referred to as the tendency of a medium to conduct ultrasound. When a sound wave travels through an object and contacts an adjacent object with a different acoustic impedance, a demarcation is formed. An example would be nerve tissue surrounded by adipose tissue. At these interfaces between objects with different acoustic impedances, reflection occurs. This is known as Snell's law. The larger the difference in acoustic impedances between structures, the greater the reflection. Interfaces that are highly reflective are displayed as white or hyperechoic. Examples include fascial planes, bones, and some nerves. Interfaces that weakly reflect ultrasound waves are darker or hypoechoic. Examples of hypoechoic structures include muscle, fat, and some nerves. Blood vessels are anechoic and appear black. The fundamental clinical challenge in UGRA is that many of the neural structures lie in close proximity to other structures that have similar acoustic impedances. Thus, it can be challenging to make a positive identification because these structures will appear similar and lack a clear acoustic interface (black on white). The great example of this is the challenge of distinguishing tendon from nerve in the distal arm or leg. Cardiac imaging is much easier secondary to the clear demarcation between blood filled chambers (black) on myocardium (whiter).

Basic Imaging Techniques:

Structures of interest can be imaged either in the short-axis (cross-section) or the long-axis. A short-axis view becomes a long-axis view when the transducer is turned 90 degrees in either direction. In general, regional anesthesiologists prefer to image nerves and blood vessels in short axis. This is because the operator has a simultaneous anterior-posterior and lateral-medial perspective. In the long axis view, the lateral-medial perspective is lost.

Two techniques have emerged in the literature with respect to needle insertion. The needle can be inserted utilizing the in-plane approach. Here, the needle is inserted parallel to the footprint of the transducer such that it is visualized in long-axis, allowing full needle visualization. Alternatively, the needle can be inserted perpendicular to the transducer footprint, generating a short-axis view of the needle. The major drawback to this out-of-plane approach is that a short-axis view of a block needle appears as a small dot that can be very difficult to see. In addition, the operator is often unable to confirm the exact location of the needle tip. There are two drawbacks to the in-plane approach. First, it is likely that the needle will need to travel through more tissue, thus possibly increasing patient discomfort. Second, given the very thin nature of the ultrasound beam, it can be very challenging to maintain constant needle imaging throughout the entire procedure.

The ten steps of peripheral UGRA are to (Adopted from ASRA Guidelines[1]):

1. Visualize key landmark structures including muscles, fascia, blood vessels, and bone
2. Identify the nerves or plexus on short axis imaging
3. Confirm normal anatomy or recognize anatomical variation(s)
4. Plan for the safest and most effective needle approach
5. Use the aseptic needle insertion technique
6. Follow the needle under real-time visualization as it is advanced toward the target
7. Consider a secondary confirmation technique, such as nerve stimulation
8. When the needle tip is presumed to be in the correct position, inject a small volume of a test solution
9, Make necessary needle adjustments to obtain optimal perineural spread of local anesthesia
10. Maintain traditional safety guidelines of frequent aspiration, monitoring, patient response, and assessment of resistance to injection

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Systematic and methodical scanning can improve target image quality and needle image quality:

ASRA recommended scanning techniques:

1. Find landmark vascular structure (possibly assisted by color Doppler), bone, or muscle
2. Find nerve or plexus on short-axis imaging (transverse scan)
3. Place machine focus on target structures
4. Place depth setting at 1 cm deep to target structures
5. Adjust gain, time gain compensation (TGC), and frequency as necessary
6. Initiate the P.A.R.T. maneuvers to optimize image quality

    a. PRESSURE: varying degrees of transducer pressure on skin
    b. ALIGNMENT: sliding movement of the transducer to define the lengthwise course of the nerve
    c. ROTATION: the transducer is turned in either a clockwise or counterclockwise direction to optimize the image
    d. TILTING: the transducer is tilted in both directions in order to maximize the angle of incidence of the ultrasound beam with the target nerve

7. Scan anticipated needle trajectory with color Doppler to identify unsuspected vascularity.

Focus

Most ultrasound machines have a focus button. The focus is usually indicated by an icon on the screen that can be moved up or down by button control. The idea is that when you place the focus of the ultrasound beam over the target, then the beam is at its narrowest point at this location. The narrow beam results in the best axial and lateral resolution for a given ultrasound frequency. In practical terms, this means that image will be the sharpest at this location.

Depth

The scanning depth is set to just 1 cm below the target because this will result in the largest image on the screen as well optimization of the frame rate. Slower frame rates can blur the image when there is needle, tissue, or transducer motion. The reason why frame rates improve with depth setting minimization is that the ultrasound waves are forced to travel less distance, meaning that they will return to the transducer in a shorter period of time. Given that the definition of frame rate is the frequency (rate) at which an imaging device produces unique consecutive images, then if you increase the number of images per second (by decreasing depth), the temporal resolution must improve. This translates into less blurriness with movement, which is a nice added feature to an ultrasound-guided block.

Gain and Frequency

As mentioned earlier, attenuation refers to the loss of ultrasound energy as it travels into the body. This loss of energy mostly results from tissue absorption that generates heat. This is why the ultrasound appearance of deeper structures appears degraded and more hypoechoic. The gain controls on the ultrasound machine try to compensate for this degradation in the ultrasound image. There is usually an overall gain button that will make the entire image

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brighter or darker as well as a set of dials called time gain compensation (TGC). These dials control the gain at specified depths. The typical settings are to increase the TGC for the deeper aspect of the image and decrease the TGC for the more superficial component. The frequency of the transducer is also directly related to the degree of attenuation. The higher the frequency of the ultrasound system, the more attenuation. The general rule is to use the highest frequency linear transducers for the superficial blocks such as the interscalene and supraclavicular. Transducers that penetrate deeply tend to be the curved transducers that are made for abdominal and obstetrical applications. These transducers are great for neuraxial and proximal sciatic blocks. Most transducers can be toggled between a range of settings for various degrees of penetration. Trial and error is the best recommendation. That is, when your target is identified, change the scanning frequency (penetration) using the machine interface and see what generates the best image.

P.A.R.T.

The above ASRA suggestions build on the aforementioned primary opening objectives. The P.A.R.T. maneuvers are very important for both optimizing the quality of the image for both the needle and target structures. There are no simple rules that mandate which one of the maneuvers will work best. Each patient is different and the operator is encouraged to systematically go through the maneuvers for every procedure.

Color Doppler

This is an amazing technology that helps to distinguish artery from vein as well as unseen vascular structures within the trajectory of the needle. **It is very important to understand a central limitation of Doppler technology.** The Doppler equation accounts for the velocity and directionality of blood. For velocity measurements to be accurate, the blood flow must be parallel to the ultrasound beam. It turns out that it is a good thing that we are not interested in velocity measurements, since most of the relationships between our ultrasound beams and blood flows are perpendicular. Take, for example, the interscalene block. Here we are imaging the carotid and IJ in short axis, so there is in essence a 90-degree relationship. If you analyze these vascular structures with color Doppler, it may appear that there is no flow (no color). Given that the patient is unlikely to be dead, this is an artifact error based on the beam and flow generating a 90-degree relationship. Obviously, we do not need color flow to identify the carotid. However, many of the branches that could be punctured such as the transverse cervical or lateral circumflex arteries may be picked up much easier with color Doppler compared to the naked eye. The simple solution to deal with the above problem is to tilt the transducer through various angles to establish a different angle relationship between an area of interrogation and the ultrasound beam. Even though the exact velocity measurements will be inaccurate, all we really care about is establishing that something either is or is not a blood vessel.

Quality Issues:

Although there are many novice behaviors and quality issues associated with UGRA, I would like to emphasize the need to confirm screen orientation. One of the significant quality compromising behaviors that we have identified at Dartmouth-Hitchcock Medical Center is confusion over screen orientation with respect to patient anatomy. To address this, the ASRA initiative on ultrasound-guided regional anesthesia has made these suggestions:

Before needle insertion, each neural structure should be referenced to key landmark structures in the anterior-posterior and lateral-medial planes. However, because of the bilateral nature of the peripheral nervous system, variations in patient positioning, differing presets of various ultrasound systems, and the nuances of individual techniques, it would be difficult to standardize the correlation of sidedness of the screen with an anatomical location. This is in contrast to transesophageal echocardiography, where, in the transgastric short-axis view of the left

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ventricle (for example), the anterior aspect of the left ventricle can be standardized to be on the bottom of the screen. Therefore, the Joint Committee recommends this simple procedure for correlation of the ultrasound screen with patient sidedness in any patient position.

1. After the application of the transducer onto the patient's skin, the landmark structure or peripheral nerve is identified. The primary operator states that the top of the ultrasound screen correlates with the patient's skin. To confirm this, pressure is applied with a finger onto the skin. This area should be visualized being compressed on the ultrasound screen.

2. For patients in any position, the operator states that screen left represents a defined anatomical aspect of the patient (e.g., cephalad). To confirm this, the primary operator again applies pressure with a finger at this defined site. A corresponding indentation should be visualized on the left aspect of the ultrasound screen. If indentation occurs on screen right the operator must turn the transducer 180 degrees. After such a correction, the operator should return to step 1 until correct imaging has been obtained and confirmed.

I hope this handout helps. If you have any comments or questions, please feel free to email me at brian.d.sites@gmail.com.

Reference:

1. Sites BD, Chan, VW, Neal JM, Weller R, Grau T, Koscielniak-Nielsen, ZJ, Ivani, G. The American Society of Regional Anesthesia and Pain Medicine and the European Society of Regional Anaesthesia and Pain Therapy Joint Committee Recommendations for Education and Training in Ultrasound-Guided Regional Anesthesia. 2009;34:40-46.

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