Ultrasound guidance in peripheral regional anesthesia

If regional anesthesia is so good, why doesn’t everyone perform it?

The benefits of regional anesthesia, with or without general anesthesia, include increased operating room efficiency, improved pain control, decreased incidence of chronic pain syndromes, and a reduction in morbidity and mortality (1 – 5). However, these benefits must be weighed against the well-appreciated negative aspects of regional anesthesia which include consumption of operating room resources, patient discomfort, block failures, nerve injury, and toxic reactions to local anesthesia. Many of these negative aspects of peripheral regional anesthesia stem from the fundamental fact that these procedures have traditionally been performed without the ability to visualize needle insertion, adjacent blood vessels, and the spread of local anesthesia. It therefore follows that general anesthesia is the most commonly performed anesthesia in the United States.

In the past five years there has been a dramatic paradigm shift within the regional anesthesia community. Anesthesiologists now have the ability to, in real time, visualize neural anatomy, needle movement, collateral structures, and the perineural spread of local anesthesia. This is all possible secondary to the use of an “old” technology: ultrasound. This lecture will highlight the overall philosophy for the use of ultrasound in peripheral regional anesthesia, offer a sample of the evidence-based medicine, and describe several techniques of commonly performed peripheral nerve blocks.

Evidence Based Medicine

The vast majority of the literature pertaining to ultrasound-guided regional anesthesia (UGRA) are case studies, feasibility studies, or descriptions of personal techniques. The first use of ultrasound to facilitate the placement of a peripheral nerve block can trace its roots back to 1978. LeGrange, et al described the use of an audible Doppler probe to locate the subclavian artery in order to facilitate the placement of a supraclavicular block (6).

The first use of two-dimensional ultrasound to facilitate a nerve block occurred in 1989 where Ting et al described the spread of local anesthesia within the axillary brachial plexus sheath (7). In 1994 Kapral et al described the use of ultrasound to facilitate single injection supraclavicular blocks and axillary plexus catheters (8).

In 1997, Marhofer et al published the first randomized and controlled trial comparing ultrasound with the conventional technique of nerve stimulation (9). In this study, 40 patients with acute hip fractures underwent a femoral nerve block with either nerve stimulation or ultrasound guidance. Ultrasound was found to decrease onset time, improve quality, and increase the success rate. In a follow up study, the same group also found that ultrasound allowed the reductions in the dose of local anesthesia when compared to nerve stimulation.
Marhofer and colleagues have demonstrated that ultrasound guidance can produce faster onset times and reductions in visual analog scale pain scores during infraclavicular block placement when compared to nerve stimulation (10).

In 2006 Sites et al compared ultrasound guidance to a traditional trans-arterial technique for the performance of an axillary plexus block (11). They found that ultrasound improved the performance times (3.2 min faster) and the success rate for surgical anesthesia (71% for trans-arterial; 100% for ultrasound).

**Rejuvenation of an unpopular block**

Surpraclavicular nerve blocks are theoretically the most attractive upper extremity blocks to perform based on the generation of rapid and profound surgical anesthetic conditions. This “spinal of the arm” can be performed with the arm in any position and utilizing a single low dose injection of local anesthesia. Although these characteristics are attractive, the supraclavicular nerve block remains unpopular secondary to the concern of injury to the subclavian artery and lung. However, with ultrasound it is possible to visualize the needle, first rib, pleura, subclavian artery, and spread of local anesthetic. Williams et al demonstrated that ultrasound-guided supraclavicular blocks can be performed faster and with superior quality in comparison to those based on conventional anatomical landmarks (12).

**False negative rate of nerve stimulation**

Every diagnostic device (including nerve stimulation) has a defined sensitivity and specificity. Most important to the anesthesiologist is the potential false negative response rate of nerve stimulation. That is, how often will the needle be in the correct perineural position and there be no corresponding motor response. This failure rate will result in inappropriate needle repositioning and the potential for unnecessary patient injury and discomfort. Beach, et al demonstrated that 13.5% of the time nerve stimulation failed to elicit a motor response despite the ultrasound confirmation of correct needle location during the performance of a supraclavicular block (13). Further defining the limitations of nerve stimulation, Choyce and colleagues reported a dramatic inconsistency between the induction of a paresthesia and the elicitation of a motor response from nerve stimulation (14). In a letter to the editor, Ben-David and Chelly suggested that this failure of nerve stimulation may result from the delivery of an asymmetric current from the needle tip secondary to varying tissue resistances (15). This would result in the “channeling” of the current away from the nerve or the passing of the current asymmetrically within the nerve. Urmey and Stanton suggested that the failure rate of nerve stimulation may have its foundation in the physical separation between sensory and motor neural elements (16). Beyond the false negative rate of nerve stimulation, evidence in volunteers suggests that different nerves in the same patient can have distinctly different responses to similar nerve stimulator settings. Regardless of the ultimate reason for variation in the motor response to nerve stimulation (or complete lack there of) the regional anesthesiologists should be alert to the limitations of nerve stimulation.
To date, there is little data on the safety of ultrasound guidance in comparison to traditional techniques. Although evidence based medicine should direct clinical management strategies, it is almost self evident that if you can visualize a) the needle, b) the target, c) structures to be avoided (i.e. blood vessels) and d) the spread of local anesthesia that many of the traditional drawbacks of regional anesthesia can be reduced or eliminated. The risk of injury related to nerve damage or systemic toxic effects of local anesthesia has been cited somewhere around 1/3000 to 1/5000 (17). Given this low rate of injury, in order to detect a significant difference between traditional and ultrasound techniques, one would require an impractical number of patients. Despite the lack of evidence-based medicine, there is one extremely attractive benefit of UGRA that theoretically should decrease patient injury: the ability to visualize the spread of local anesthesia. The operator has the critical ability to see where the drug is spreading. If the drug is spreading circumferentially around the nerve, it is unlikely to be either intraneuronal or intravascular. This “safety net” is not available with traditional approaches.

**Terminology:**

Ultrasound is defined as sound waves that are at a frequency of 20,000 cycles per a second or Hertz (Hz) or higher. Most transducers used for UGRA are between 7 and 15 million Hz or 7 to 15 megahertz (MHz).

An ultrasound wave is produced when an electrical signal is placed across a piezoelectric crystal that forces the crystal 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 \( c = (\lambda) \cdot (f) \), where \( c \) = the propagation velocity and is presumed to be 1540m/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.

What gives us “targets” for UGRA is 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. The larger the difference in acoustic impedances, then the greater the reflection. Objects that are highly reflective are displayed as white or hyperechoic. Examples include fascial planes, bones, and some nerves. Objects 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.

**Basic Clinical Pearls:**

Structures of interest can be imaged either on the short axis (cross-section) or the long axis. A short axis view becomes a long axis view when the probe is turned 90 degrees in either direction. In general, regional anesthesiologists prefer to image nerves and blood vessels on 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 (18). The needle can be inserted utilizing the in-plane approach. Here, the needle is inserted parallel to 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 unable to confirm the exact location of the needle tip.

**Indications:**

Ultrasound is used for anatomical evaluation and to facilitate the performance of both neuraxial and peripheral nerve blocks. This technology may be particularly useful in patients with obscure anatomical landmarks, coagulopathy, neural pathology, and severe extremity trauma. Further, ultrasound provides an opportunity to visualize individual anatomical variations. UGRA is typically performed by anesthesiologists and pain specialists in a procedure room or within the operating room.

The ten steps of peripheral UGRA are to:

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

Contraindications:

There are no known absolute contraindications to the use of ultrasound. With respect to safety, the United States Food and Drug Administration has stated, “Even though there are no known risks, ultrasound energy heats the tissues and may have other biological effects. It can also produce small pockets of gas in body fluids or tissues (cavitation). The long-term effects of tissue heating and cavitation are not known” (18)

The Future:

The major clinical challenge of UGRA is the ability to simultaneously visualize the needle, the nerve, and the spread of local anesthesia. This challenge is based on the limitations of the current state of the art two-dimensional (2-D) imaging. Subtle movements of the needle or probe can result in the disappearance of one of the critical structures. With the new application of three-dimensional (3D) imaging, the operator has the theoretical ability to see all structures regardless of the approach used to insert the needle (i.e. in-plane vs. out-of-plane). Additionally, new adhesive ultrasound gels and probe holders are emerging that will secure the probe and thus reduce ergonomic challenges. Finally, a new generation of needles will be available which are insulated and more hyperechoic.

References


