4. NERVE STIMULATION AND ULTRASOUND THEORY

NERVE STIMULATION

The concept of using an electric current to generate muscle contractions via nerve stimulation is nearly a century old, although the theory behind peripheral nerve stimulation is still poorly understood. Actual electrical stimulation of nerves to evoke a muscle response was first accomplished in 1850 by Herman von Helmohlz during experiments on isolated pieces of nerve and muscle tissues. In 1912 Dr VG Perthes described using a nerve stimulator to perform peripheral nerve blocks. Recent technological advances have made the use of nerve stimulation equipment easier and far more accurate than in past decades.

Ideally, a peripheral nerve stimulator (PNS), in combination with an insulated needle, provides objective information on needle location by eliciting muscular twitches in muscle groups served by targeted nerves. At the most basic level, a PNS works by generating an electric current and transmitting it via a needle insulated along most of its length, leaving only the needle tip exposed to deliver the current in very close proximity to targeted nerves. A few additional concepts, however, are essential to understanding how the PNS is used in peripheral nerve block procedures. For a nerve to be stimulated, its threshold potential must be achieved. To accomplish this, electrical energy is applied in the specific amount for electrons to depolarize the nerve cell membrane (threshold depolarization), causing shifts in intracellular and extracellular sodium and potassium ions. The impulse is then propagated along the nerve via saltatory conduction.

The threshold level of energy for depolarization of the nerve can be achieved by applying a high current over a short period of time or a lower current over a longer period of time; this is the most basic way to understand the concepts of "reobase" and "chronaxie." Reobase is defined as the minimum current necessary to achieve threshold potential over a long pulse. Chronaxie is the minimum duration of stimulus at twice the reobase for a specific nerve to achieve threshold potential. Certain nerves have a different chronaxie based on their physical properties (myelination, size, etc). Also, certain patient conditions, such as diabetes, have an effect on chronaxie. Large A-alpha motor fibers are more easily stimulated than are the smaller A-delta and C fibers, which are responsible for pain. The normal pulse duration needed for depolarization is between 50 and 100 microseconds for A-alpha fibers, 170 microseconds for A-delta fibers, and 400 microseconds for C fibers. By applying this knowledge, the duration of the PNS pulse can be adjusted to keep it above the normal A-alpha range and below the A-delta and C fiber level. The stimulation of motor A-alpha fibers provides muscle twitch information while avoiding A-delta and C fibers that cause pain, thus allowing for a more comfortable nerve stimulation experience for the patient. If the current is too high (eg, > 1.0 mA), the PNS may no longer be able to differentially stimulate nerve fibers.

By understanding the concepts of reobase and chronaxie, adjustments can be made to some nerve stimulators to achieve stimulation of targeted nerve fibers only, or of nerves that may not otherwise be stimulated with a PNS. For example, in diabetic patients with a prolonged history of elevated blood glucose levels, nerves may become glycosylated, making stimulation difficult. In these patients, increasing the duration of the electric pulse may be the only way to achieve a minimum current of 0.5 mA for stimulating a nerve.

Another important difference between a modern PNS (Figure 4-1) and older models is the ability to provide constant current output. According to Ohm's law, $I=V/R$, where I is the current, V is the potential difference in volts, and R is the resistance or impedance. If resistance (impedance) were completely removed from the equation, then current would equal the potential difference. In some modern PNS models, this equilibrium is achieved by a constant current generator that automatically adjusts the current set by the user. The constant output maintains the same level of needle tip current regardless of the impedance of body tissue and PNS circuit connections.

Figure 4-1. HNS 12 nerve stimulator manufactured by B Braun Medical Inc (Bethlehem, Pa; used with permission)

The ability to control the intensity and frequency (2 Hz) of the current being applied is an important aspect of a PNS. Using a higher current for initial nerve stimulation allows for earlier identification of the nerve's location. Decreasing the current once stimulation has been achieved allows the operator to place the needle in close proximity to the target nerve. Constant stimulation of the nerve below 0.5 mA but above 0.2 mA generally results in a safe, reliable block. The commonly used 2-Hz frequency allows for rapid manipulation of the needle to help locate the nerve.

ULTRASOUND GUIDANCE

Another recent technological advance of extraordinary benefit to the regional anesthesiologist is the portable ultrasound machine (Figure 4-2), which allows for real-time visualization of target nerves, as well as surrounding arteries, veins, muscle, and bone. Ultrasound technology also provides the ability to validate external landmarks against internal anatomy. Furthermore, the advantage of needle guidance under direct visualization allows the operator to avoid vascular structures and more accurately inject local anesthetic.

Most modern ultrasound machines have the ability to provide visualization of both superficial and deep structures based on the type of probe used. Basic understanding of ultrasound theory is vitally important for the safe use of this technology. Ultrasound waves are created by a number of vibrating piezoelectric crystals contained in the head of a transducer attached to the ultrasound machine. Ultrasound waves penetrate tissues to different depths based on the probe frequency. Higher frequency probes, which emit waves at a frequency between 5 and 13 MHz, provide images with greater resolution but do not penetrate deeply into tissue. Lower frequency probes, with frequencies between 2 and 5 MHz, can penetrate tissue deeply (up to a depth of 30 cm), but the resolution is far less than that of the high frequency probes.

The image produced by the ultrasound machine depends on both the tissue's density and its ability to reflect ultrasound waves back to the transducer (ie, the tissue's echogenicity). Hyperechoic structures are those with a greater propensity to reflect ultrasound energy, and hypoechoic structures tend to absorb this energy. Hyperechoic structures (bone, nerves below the clavicle, vascular walls, and other connective tissues) therefore appear brighter on the screen, and hypoechoic structures (nerves above the clavicle, blood vessel lumens, lung, and other fluid-filled structures) appear darker (Figure 4-3). Acoustic impedance refers to the reduction in ultrasound wave energy that occurs as the wave passes through structures, which accounts for the depth limits on ultrasound penetration of tissues.

Figure 4-2. Micromaxx Ultrasound Machine manufactured by SonoSite, Inc (Bothell, Wash)

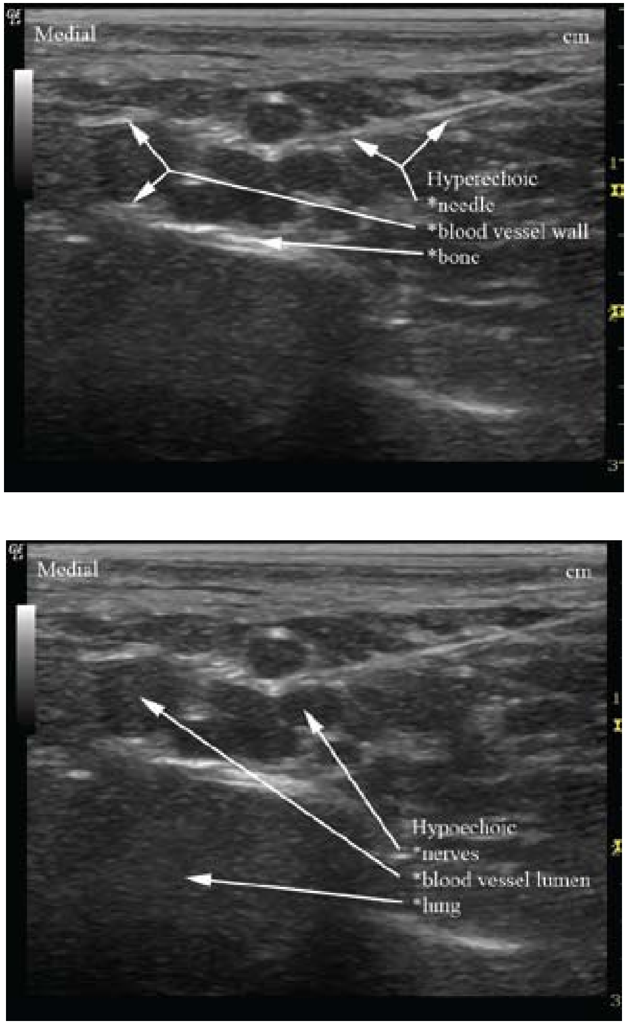

Figure 4-3. (a) Hyperechoic structures and (b) hypoechoic structures seen on ultrasound

The operator's knowledge of anatomy is fundamental to the safe practice of ultrasound-guided regional anesthesia. Once the nerves are identified, the block is performed with the needle under direct visualization in the long-axis view (in plane) and the nerve in the short-axis view. Some experienced ultrasound operators prefer the out-of-plane technique (with the needle in short-axis view) for some blocks. Although this technique results in shorter needle distances to targeted nerves, it does not allow visualization of the entire needle during performance of the block. Both techniques allow the needle to be directed away from potentially dangerous areas and the local anesthetic to be deposited in multiple locations around the nerve for a safe, successful regional nerve block.

If the operator is uncertain about the needle tip's proximity to imaged structures, hydrodissection under ultrasound guidance may be used. This technique involves slowly injecting several milliliters of local anesthetic (or other fluid such as saline) to more precisely define the needle tip location. For example, if the injected fluid spreads away from the targeted nerve, the needle tip is probably external to the nerve sheath. Injected hypoechoic fluid also may enhance image clarity of the targeted structures.

Many compact ultrasound machines are currently available with updated software that improves image quality to a standard until recently obtainable only in large, cumbersome, and expensive machines. Thorough familiarization with the ultrasound machine being used and its available options is necessary to obtain the best possible image for facilitating needle placement. Many ultrasound machine options are available, but most machines include a few basic image adjustment features:

- Depth control: allows the user to set a tissue depth (in cm) that the ultrasound waves will penetrate.
- Gain control: allows the user to adjust the screen grayscale contrast, thus alleviating unnecessary interference from poor tissue conduction properties, poor probe-to-tissue interface, or other problems.
- Doppler mode: allows for differentiation of structures containing moving fluid such as arteries and veins.
- Focus setting, including three basic image resolution settings:
  - o RES (resolution): provides the best detail of superficial structures.
  - o GEN (general): provides the best compromise for visualizing structures in detail at greater depth.
  - o PEN (penetration): provides the best image of deep structures, although image detail is significantly degraded.
- Zoom: magnifies image up to 200%.
- Image freeze and save: allows still pictures of ultrasound blocks to be saved for documentation of the block procedure.
- Patient data screen: allows patient demographic data to be associated with saved ultrasound images.

Other advances in ultrasound software, such as clearer images through signal harmonics and three-dimensional ultrasound imaging, continually improve the value of ultrasound technology as a tool in regional anesthesia. The availability of this technology on a laptop, easily portable in the austere battlefield medical environment, is a particularly exciting advancement.

CONCLUSION

Whether nerve stimulators, ultrasound machines, or both are used to perform regional anesthesia, a basic understanding of how these technologies function when used on live tissues is an important addition to, but not a replacement for, detailed anatomical knowledge. This technology can only confirm and refine correct needle placement for regional blocks; it should never be considered a substitute for the physician's understanding of the anatomical basis for each block. Both tools likely enhance patient safety and improve nerve block success when used by a trained regional anesthesiologist. *Note: The technology shown to demonstrate concepts in this chapter should not be considered as an endorsement of these products or companies.*