▽ Editorial

Peripheral Nerve Stimulators: Cracking the Code—One at a Time

All right, so perhaps nerve stimulators are not as complicated as genetics. But at times, at least, we seem to have made it that way by failing to adequately study the intricacies of nerve stimulation and then guide the industry in developing better tools for nerve localization. While our understanding of various aspects of nerve stimulation is clearly growing, it is far from complete. Clinicians who use nerve stimulation on a daily basis often discuss the lack of consistency and the "finicky" nature of nerve stimulation, whereby a motor response can suddenly diminish or disappear entirely without a plausible explanation. In the meantime, recent technological advances in circuit design of nerve stimulators have made recommendations regarding the current intensity in older texts almost obsolete. In this editorial, I briefly comment on some recently published data on peripheral nerve stimulators and discuss how the study by Tsui et al., published in this issue of *Regional Anesthesia and Pain Medicine*, adds to our current understanding of nerve stimulation.

Accuracy of Current Delivery

Accuracy of current delivery in nerve stimulators is far from ideal. In a recent bench-test study of nerve stimulators, several units substantially erred, particularly in the low-current range, where precision of the nerve stimulator is crucial, as the needle is in close relationship to the nerve.[1] Indeed, in modern practice, stimulating currents of 0.1 mA to 0.5 mA are commonly used to ensure that the needle is in close proximity to the nerve before injecting local anesthetic.[2-4] Obviously, a nerve stimulator that delivers less current than selected may lead the operator to continue advancing the needle toward the nerve, when in fact the needle is already close to the nerve. Advancing the needle further may lead to mechanical injury or an intraneuronal injection of local anesthetic.[5] In contrast, a nerve stimulator that delivers a current higher than that selected may result in injection of local anesthetic when the needle is, in fact, remote from the nerve, thus increasing the chance of a failed block.[6] Fortunately, this lack of precision is mostly limited to older models; most newer nerve stimulators are based on constant-current circuitry and deliver the dialed current with much greater accuracy.

Current Duration

Two important electrophysiologic variables that may affect nerve stimulation are the rheobase (the minimum current required to stimulate a nerve with a long pulse) and the chronaxie (the duration of the stimulus required to stimulate the nerve at twice the rheobase).[6,7] Because peripheral nerves vary in size (large, heavily myelinated A α motor fibers vs. smaller, unmyelinated C fibers), it stands to reason that their chronaxie vary as well. It is surprising, then, that there are no manufacturing standards for duration of the stimulating current. There is a wide disparity in duration of the stimulus among various models of nerve stimulators; the duration of the current may vary as much as 20-fold among various models

Accepted for publication March 4, 2004.
doi:10.1016/j.rapm.2004.03.003

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and makes of nerve stimulators.[3] Because the duration of the current determines the amount of energy delivered to the tissue, clinicians should be aware of this inconsistency. This is explained by the fact that the total energy delivered to the nerve(s) is greater with stimuli of longer duration and is described by the equation E (energy; nC) = I (current intensity; mA) × t (duration of application; μs). For example, when set at a current of 1.0 mA, a stimulus duration of 1.0 ms will deliver 10 times more energy than a stimulus of 0.1 ms (1,000 nanoCoulombs [nC] vs. 100 nC).

Maximum Voltage Output

With constant-current technology, the circuit senses the difference between the current set by the user and the actual current delivered by the unit. When the stimulating current sensed by the unit is lower than that set by the user, circuitry in newer stimulators automatically compensates by increasing voltage output. This scenario may arise in clinical practice when abnormally high impedance is encountered due to excessively dry skin or a desiccated surface electrode.[8] Under these circumstances, a voltage as high as 336 volts may be delivered by some peripheral nerve stimulators to maintain a selected level of current. This may be painful to the patient because, despite delivering a low stimulating current, excessive voltage is applied to the nerve over a very small area by the tip of the stimulating needle, resulting in high current density.[8] In addition, high-output peripheral nerve stimulators (e.g., 70 mA/500 volts) used for monitoring the neuromuscular block have been reported to burn skin under certain circumstances.[9] Although a similar complication has not been reported after using nerve stimulators for nerve block, it would seem prudent to avoid applying such high current or voltage output in the vicinity of the nerves.

Ideal Position of Cutaneous Electrode

The purpose of a surface electrode (return; positive) is to complete the electrical circuit, and its placement on the patient's body may influence current flow. Although most investigators agree that location of the surface electrode is important for accurate nerve localization, opinions vary as to its optimal location. Some teach that the surface electrode should be placed as close to the site of needle insertion as possible,[10,11] whereas others suggest that it should be placed in an area remote from the block needle.[12] However, more recent data suggest that the site of placement of the cutaneous electrode is actually not important when using a constant-current output nerve stimulator.[13]

Duration of the Stimulating Current

To stimulate motor fibers of a mixed nerve (plexus) without stimulating sensory components and possibly causing discomfort to the patient, it has been suggested that a short-duration current (≤0.1 ms) be used for nerve stimulation in regional anesthesia.[12,14] However, more recent data suggest that duration of current does not have a significant effect on the degree of discomfort during nerve stimulation.[15] In fact, increasing current duration does not affect the level of discomfort during nerve localization so long as intensity of the motor response is kept constant.[13] Consequently, the greater the amount of energy delivered to the nerve, the more forceful the motor response will be, and the greater the discomfort will be to the patient.

Stimulating Current and Needle-Nerve Distance

The stimulating current at which a needle is sufficiently close for a successful block, yet still a safe distance from the nerve to avoid injury is controversial. Although many investigators suggest obtaining a visible motor response at less than 0.5 mA (100 μs), some warn that stimulation at 0.2 mA may indicate intraneural placement of the needle.[16] A more recent study in volunteers found that stimulation below 0.2 mA is not common and perhaps should not be routinely sought, because stimulation between 0.2 and 0.5 mA results in accurate needle placement.[13]

Nerve Stimulation and Risk of Nerve Trauma

The debate between whether the paresthesia or the nerve-stimulation method is safer for avoiding nerve injury is decades old. Proponents of the nerve-stimulation method claim that the ability to elicit a motor response before the needle contacts the nerve makes this method theoretically safer. Conversely, proponents of the paresthesia method claim that absence of nerve stimulation does not guarantee intraneural needle placement, as supported by reports of paresthesia (therefore, mechanical needle-nerve contact) in the absence of motor response.[3,17] No randomized clinical trials have compared the complications of the two methods; however, available data and case reports suggest that nerve injury can occur with either method even in the hands of experienced anesthesiologists.[18] Instead, avoidance of pain and excessive pressure (resistance) during injection of local anesthetic may be more objective and controllable predictors of intraneural injection than the method of nerve localization used.[19-21]

In their article in the current issue of *Regional Anesthesia and Pain Medicine*, Tsui et al.[22] nicely show the complexity of the electrophysiologic milieu necessary for successful nerve depolarization. They offer a plausible explanation for the inconsistency of nerve stimulation and an electrophysiologic explanation for the cessation of motor response that occurs immediately following injection of even a small amount of local anesthetic solution. In their experiment in a porcine model, injection of 0.9% solution of NaCl abolished the motor response, while a consequent injection of 0.5% dextrose reestablished the effective stimulation. Their accompanying in vitro experiment shows that injections of solutions, such as 0.9% NaCl or 0.5% dextrose, cause a change in the electrical field at the needle-tissue interface. This suggests that effective nerve stimulation is sensitive to changes that occur at the needle-tissue interface, such as a change in the angle of the needle or injection of local anesthetic. The net effect appears to affect the current density at the tip of the needle or a path of the electric current, ultimately resulting in a change of the quality of the motor response. This is analogous to an electrical circuit, where, if in a complicated array of resistors and capacitors connected in parallel the resistance and capacitance of a few components is changed, the intensity of the current flowing through the rest of the circuit components will inevitably change.

Nerve stimulators have become a staple for a more objective and exacting approach to the practice of peripheral nerve blocks; essentially all modern research publications, instructional materials, and textbooks on regional anesthesia suggest the nerve stimulation method.[23] Regardless, our understanding of the intricacies of nerve stimulation is still not complete, and books and instructional texts on regional anesthesia still have conflicting recommendations regarding many technical aspects of nerve stimulation. It is for that reason that contributions to our understanding of the principles of nerve stimulation and the factors that influence its clinical application in regional anesthesia—such as that by Tsui et al.—are highly valuable and should be most welcome.

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