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Electrical Nerve Stimulation

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2.1. Introduction

Electrical nerve stimulation is widely used for nerve localization during peripheral nerve blockade. An accurate constant current stimulator is necessary for reliable results. Electrical impulses excite nerves by inducing a flow of ions through the neuronal cell membrane, with subsequent action potential generation. The nerve membrane depolarization results in either muscle contraction or paresthesia, depending on the type of stimulated nerve fiber (motor or sensory), which is consistent with the nerve's distribution.

The general procedure for nerve stimulation with peripheral nerve blocks is as follows:

- The stimulating needle is connected to the cathode.
- After the skin is disinfected, the needle is advanced towards the nerve with the stimulator at a relatively high current intensity (1–2 mA) and with a pulse width of 100 to 200 μ s.

- This higher current amplitude is necessary to stimulate the nerve at some distance from the needle (once twitches are seen, the needle is likely 1–2 cm away). Care should be exercised to avoid discomfort to the patient.
- The current intensity is then decreased as the needle approaches the nerve and the muscle twitch increases; the current at lowest twitch response (i.e., threshold current) is then recorded (usually at 0.4–0.5 mA).
- Attempting to observe a twitch at lower intensities (<0.3–0.4 mA) may result in inadvertent intraneural injection and is not necessary to increase success.
- Perineural catheters generally require more intense stimulation, especially if normal saline is used for space expansion; the ionic conductance will disperse the electrical stimulus.
- Once the acceptable threshold current is reached, aspiration for potential intravascular placement is performed. With a negative aspiration a test injection of local anesthetic or normal saline (1–2 mL) is performed. The muscle twitch should diminish following the test injection (Raj test).
- The mechanism of the Raj test was previously thought to be due to displacement of the nerve by the injectate, thereby making the minimal current insufficient to stimulate the nerve. This interpretation resulted in faulty positioning of catheters following advancement. A recent interpretation of the Raj test suggests that ionic solutions influence the response to nerve stimulation. The use of nonconducting solutions (e.g., dextrose 5% in water) for testing needle/catheter placement, which maintain the motor response, may prevent the unnecessary and faulty advancement of needles/catheters due to current leakage.
- With pure sensory nerves, the response will be a radiation of paresthesias with each pulse along the distribution of the nerve. Additionally, the pulse width used for nerve localization should be somewhat higher (300 μ s–1 ms).

Recent applications of electrical stimulation include percutaneous electrode guidance, epidural catheter placement guidance, and peripheral catheter placement for continuous peripheral nerve block. Sections 2.2 and 2.3 in this chapter do not imply that the mechanisms of nerve stimulation are completely understood, and it is likely that some concepts may vary with current literature. In addition, the newly expanded application of electrical stimulation within the epidural space is addressed at length in Chapters 18 and 20.

2.2. Electrophysiology

The characteristics of the electrical impulse will determine its ability to stimulate a nerve, and the quality of stimulation will be affected by the polarity and type of electrode, the needle–nerve distance, and by potential interactions at the tissue–needle interface.

2.2.1. Characteristics of Electrical Impulses

Theoretically, a painless motor response can be produced using a low current with a short pulse width, as motor nerves are the main effectors. Conversely, the higher the current, the less preferential the stimulation is for motor nerves. Recent literature suggests other factors may also contribute to pain during peripheral nerve block, including withdrawal and repositioning of needles and strength of muscle contraction.

2.2.1.1. Current Intensity and Duration

- With applications of square current pulses, the total charge (Q) applied to a nerve equals the product of the current intensity (I) and the duration (t): $Q = I \times t$

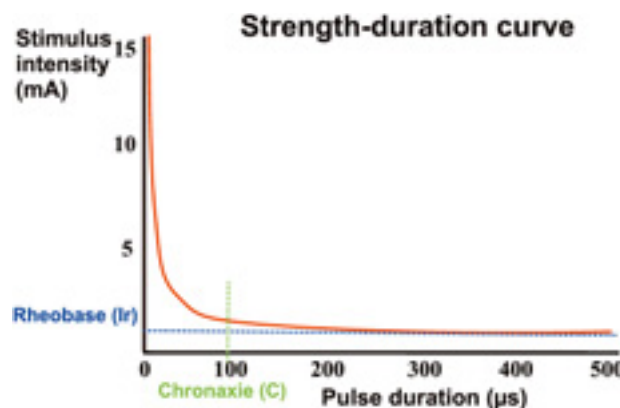


Figure 2.1. Stimulation curve plotting current intensity and pulse duration. (Reprinted from Reg Anesth; 10; Pither CE, Raj PP, Ford DJ. The use of peripheral nerve stimulators for regional anesthesia: A review of experimental characteristics, technique, and clinical implications; 49–58;10:1985. With permission from the American Society of Regional Anesthesia and Pain Medicine).

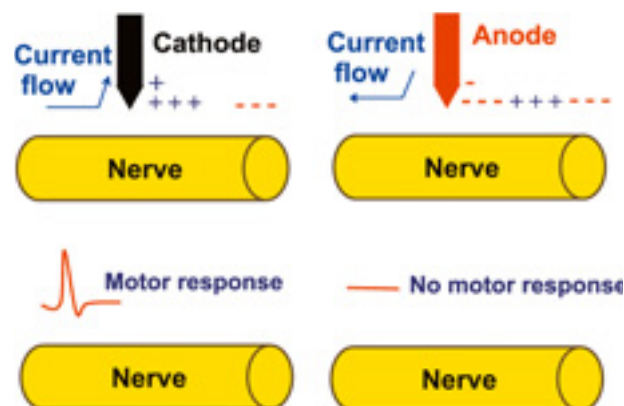


Figure 2.2. Preferential cathodal stimulation. (Reprinted from Reg Anesth; 10; Pither CE, Raj PP, Ford DJ. The use of peripheral nerve stimulators for regional anesthesia: A review of experimental characteristics, technique, and clinical implications; 49–58;10:1985. With permission from the American Society of Regional Anesthesia and Pain Medicine).

- The typical stimulation, or excitability, curve that is produced when plotting intensity versus duration results from the relationship: $I = I_r(1 + C/t)$ (Figure 2.1).
 - ♦ I_r is the rheobase: the minimum current intensity for nerve depolarization using a long pulse width.
 - ♦ C is the chronaxie: the pulse duration at an intensity twice the rheobase.
 - This variable differentiates the stimulation threshold for various nerve fibers (i.e., larger $A\alpha$ motor fibers have shorter chronaxie and are the easiest to stimulate).
- The pulse width can be varied to target different fiber types (large $A\alpha = 50\text{--}100\mu\text{s}$, smaller $A\delta = 150\mu\text{s}$, C sensory = $400\mu\text{s}$).

2.2.1.2. Rate of Current Change

- Regardless of stimulus intensity, a rate of current change that is too low will reduce nerve excitability.
- Long subthreshold intensity or slowly increasing rates will inactivate sodium conductance and prevent depolarization; this is termed *accommodation*.

2.2.2. Polarity of Stimulating and Returning Electrodes

Direct electrical current flowing through two electrodes on a given nerve will stimulate the nerve at the *cathode* (negative electrode) and resist excitation at the *anode* (positive electrode).

- Negative current from the cathode reduces voltage outside the neuronal cell membrane, causing depolarization and an action potential; the anode injects positive current outside the membrane, leading to hyperpolarization.
- Preferential cathodal stimulation (Figure 2.2) refers to the significantly reduced (one third to one quarter) current that is required to elicit a motor response when the cathode is used as the stimulating electrode.
 - ♦ The cathode is usually attached to the stimulating needle/catheter; the anode to the patient's skin as a returning electrode.
 - ♦ When using a constant current output nerve stimulator, the distance between the anode and cathode is not of particular importance, as previously thought.

2.2.3. Distance–Current Relationship

Generally, as the distance increases between the nerve and the stimulating electrode, a higher stimulus current is required. Because the current varies with the inverse of the square of the distance, a much larger stimulating current will be required as one moves away from the nerve (Figure 2.3). A shorter pulse width requires more current to stimulate the nerves at greater distances, but is a better discriminator of nerve–needle distance (Figure 2.4).

- Coulomb's law describes the relationship between distance and current intensity:

$$I = k(i/r^2)$$
 - ♦ I = current required; k = constant; i = minimal current; r = distance from nerve.
 - ♦ Initially, 1 to 2 mA (pulse width 100–200 μ s) is used to elicit a response superficially, with the accurate placement from needle advancement indicated by an 0.2 to 0.5 mA response.
 - ♦ The potential for intraneural injection is increased as the current approaches 0.2 mA (the author now uses 0.4 mA as a limit) responses, as the electrode may be too close to the nerve.
- Percutaneous electrode guidance designates the optimal point on the skin for needle insertion in a simple, reliable, and noninvasive manner.
 - ♦ Commercially available surface electrodes with 0.5 cm diameters (Figure 2.5) connect to the negative electrode of the nerve stimulator.
 - ♦ Smaller electrodes result in greater current applied to the skin and, therefore, more tissue is affected, which may be uncomfortable for the patient.
 - ♦ The initial current used is generally 5 mA with a 200- μ s pulse width, and the current is reduced to a minimal response as with the usual technique (2–8 mA currents have been used for the more superficial location of peripheral nerves).
 - ♦ With the introduction of ultrasound, the use of this method for guiding needle insertion is diminishing.

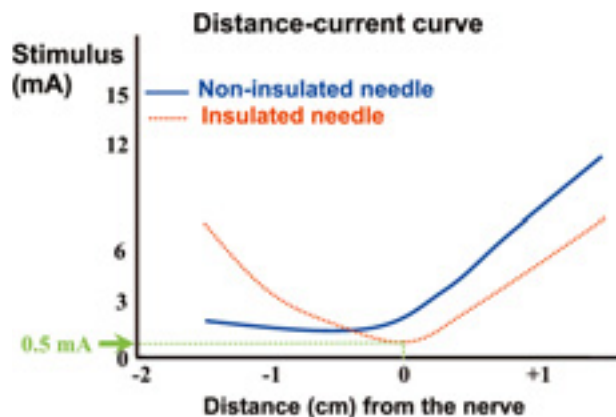


Figure 2.3. Distance–current curve. Noninsulated needles require more current than insulated needles at the same distance from the nerve and have less discrimination of distances as the needle approaches the nerve. The current threshold is minimal (0.5 mA) for insulated needles when the needle is on the nerve. (Reprinted with permission from Reg Anesth; 9; Pither CE, Ford DJ, Raj PP. Peripheral nerve stimulation with insulated and uninsulated needles: efficacy and characteristics; 42; ©1984. With permission from the American Society of Regional Anesthesia and Pain Medicine).

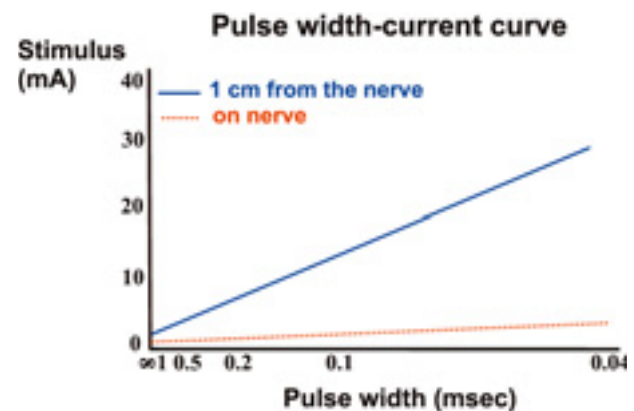


Figure 2.4. Current intensity at different pulse widths. A shorter pulse width requires more current with greater nerve–needle distances, but is a good discriminator. (Reprinted from Reg Anesth; 9; Ford DJ, Pither CE, Raj PP. Electrical characteristics of peripheral nerve stimulators: implications for nerve localization; 73–77; ©1984. With permission from the American Society of Regional Anesthesia and Pain Medicine).



Figure 2.5. Surface electrodes for percutaneous electrode guidance. The large diameter (0.5 cm) electrodes attach to the negative electrode of the nerve stimulator.

2.2.4. Current Density of Electrodes and Injectates

At the needle tip, the conductive area for current flow will modify the current density and response threshold. Small conductive areas will condense the current and reduce the threshold current for motor responses. The needle/catheter–tissue interface can affect the density as the area of conductance can change with changing injectates (e.g., ion conductance variation) or tissue composition. The needle is an extension of the stimulating electrode. Conducting and nonconducting solutions vary significantly in their effect on the current at the needle/catheter tip.

2.2.4.1. Electrodes

- Types of electrodes include insulated and noninsulated needles and stimulating catheters.
- Insulated needles have nonconducting shafts (e.g., Teflon) that direct the current density to a sphere around the uncoated needle tip (i.e., small conducting area allowing low threshold current stimulation).
 - ◆ The threshold current is minimal when the needle tip contacts the nerve and is approximately 0.5 to 0.7 mA with a pulse width of 100 μ s when nerves are 2 to 5 mm away.
- Stimulating catheters are similar to insulated needles, except for the requirement of a much higher threshold current with the use of saline for determining correct placement and/or dilating the perineural space.
- Noninsulated needles are bare metal and transmit current throughout their entire shaft; the current density at the tip is therefore much lower than with insulated needles.
 - ◆ Often more than 1 mA is required for nerve stimulation with noninsulated needles.

2.2.4.2. Injectates

- During nerve stimulation, the traditional test (Raj test) used for nerve localization includes a test injection of local anesthetic or normal saline, which abolishes the muscle twitch response.
- This effect was previously thought to result from the force of the fluid causing nerve displacement away from the needle tip. It is now known to be due to the conduction properties of these solutions (Figure 2.6).
- The use of nonelectrolyte/nonconducting injectates, for example, dextrose 5% in water (D5W), reduces the conductive area and increases the current density at the needle tip with resulting maintenance or augmentation of the motor response at a low current (<0.5 mA). Electrical resistance will also change upon injection of different injectates. The lack of such a change may serve as a warning sign of intravascular placement.
- Clearly, nerve stimulation is sensitive to changes at the tissue–needle/catheter interface. In a physiological context, the electrical field surrounding the needle tip and the

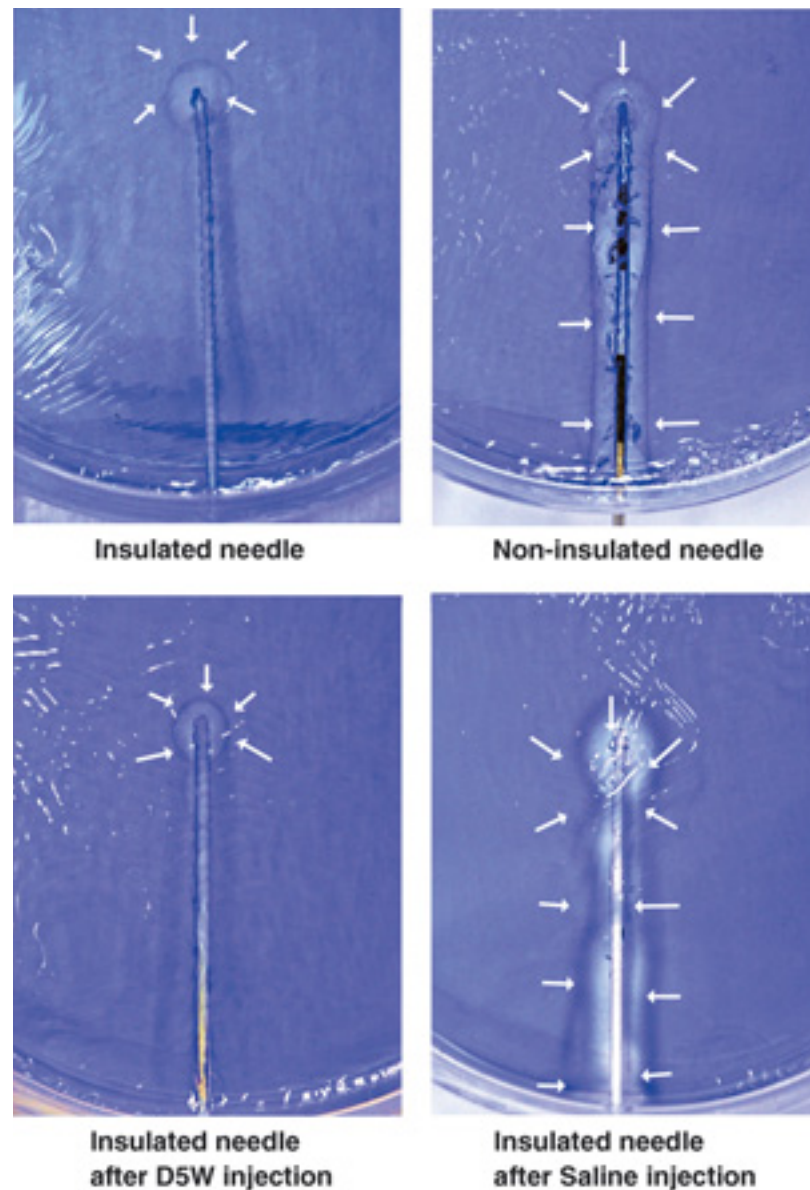


Figure 2.6. Conductive properties of electrodes and injectates. Insulated needles have a small conducting area, allowing low threshold current stimulation, while noninsulated needles transmit current through their entire length and have a lower current density at the tip. Conducting solutions (e.g., saline or local anesthetic) increase the conductive area at the needle tip and increase the threshold current requirement, whereas nonconducting (nonelectrolyte) solutions (e.g., D5W) reduce the conductive area at the tip and increase the current density. The motor response from nerve stimulation after D5W injection remains the same (or is augmented) to that during needle/catheter placement. (Reprinted from *Reg Anesth Pain Med*; 29; Tsui BC, Wagner A, Finucane B. Electrophysiologic effect of injectants on peripheral nerve stimulation; 189–193; ©2004. With permission from the American Society of Regional Anesthesia and Pain Medicine).

conductive area generated by the needle tip are non-uniform, which occasionally leads to unstable electrical stimulation responses.

- During advancement of the stimulating catheter, it may be beneficial to use nonconducting solutions for dilating the perineural space, as this may reduce the current leakage and promote continued motor response during advancement as long as the catheter tip stays in close proximity to the nerve.

2.3. Useful Features of Equipment Variables

There are many different makes and models of nerve stimulators on the market and anesthesiologists should familiarize themselves with the equipment available in their own institution.

2.3.1. Constant Current Output and Display

- Most modern nerve stimulators are now produced to utilize constant current (Figure 2.7), rather than the traditional voltage systems; this allows the current to remain the same regardless of resistance variation.
 - ♦ Most machines can be adjustable in frequency, pulse width, and current strength (milliamperes).
- Clear digital displays (monitors) show the current delivered to the patient and the target current setting.
 - ♦ Some stimulators have low (<6 mA) and high (<80 mA) output ranges for increased accuracy during localization of peripheral nerves and monitoring neuromuscular blockade, respectively.
- Note that the amplitude of currents required for *epidural* stimulation are much higher (1–17 mA) than the low output range of some peripheral nerve stimulators, therefore, most stimulators used solely for peripheral nerve blockade will not be suitable for this neuraxial application.



Figure 2.7. Many constant current nerve stimulators are on the market and will vary in their current output ranges.

2.3.2. Variable Pulse Width and Frequency

- Pulse width (i.e., duration of pulse) determines the amount of charge delivered and enables selective stimulation of different nerve fibers (Figure 2.1).
 - ♦ For instance, sensory fibers are more effectively stimulated with longer pulse widths (400 μ s) than motor nerves (50–150 μ s).
 - ♦ Some devices allow width ranges from 50 μ s to 1 ms for high variation and selectivity depending on the specific nerve block location.
 - ♦ A recent study (Urmey and Grossi, 2006) suggests that utilizing pulse width variation (rather than constant width as commonly practiced) through sequential electric nerve stimuli (SENS) can increase sensitivity without compromising specificity of nerve location (see Figure 2.4, which illustrates the ratio of stimulus to pulse width at different needle–nerve distances).
 - By programming a nerve stimulator to deliver a repeating series of alternating sequential pulses of 0.1, 0.3, and 1 ms at 1/3-second period intervals between pulses, with usual current adjustments, the following results:
 - At a greater distance from the nerve, only higher durations (e.g., 0.3 and 1 ms) would stimulate the target nerve and result in 1 or 2 motor responses per second.
 - Three twitches at 0.5 mA or less indicates that three pulses were delivered successfully for motor responses and signified the conventional endpoint for nerve location. However, this technique may increase the incidence of paresthesias due to the use of long pulse widths.
 - The frequency of stimulation will affect the advancement rate of the needle, as slow stimulation frequencies may cause the target nerve to be missed due to inappropriate timing.
 - ♦ Optimal pulse frequency variation is 0.5 to 4 Hz (number of stimuli per second), with most operators using 2 Hz.

2.3.3. Specialized Polarity Electrodes

- A specialized male connector designed to fit in the female conducting portion of the stimulating needle is a newer and common feature of nerve stimulators.



Figure 2.8. Foot pedal or hand-held remote control adjusters of current output.

2.3.4. Disconnection and Malfunction Indicators

- Indicators displaying the status of battery power as well as those warning of incomplete circuitry or pulse delivery failure are essential components of the machinery.

2.3.5. Other Accessories

- Foot pedal or small hand-held remote control adjusters of current output (Figure 2.8).
- Probes (commercially available) for the performance of surface nerve mapping during percutaneous electrode guidance procedures (Figure 2.5).

2.4. Practical Considerations

2.4.1. Documentation

- Documentation of the procedure and performance of the peripheral nerve block is very important for patient care and quality assurance, as well as for research and medicolegal purposes.
- A useful, standardized, procedure note form has recently been developed and can easily be adapted to regional anesthesia procedures.

2.4.2. Population Considerations

- Elderly, obese, and diabetic patients may have structural changes in nerves such that higher initial current thresholds may be required.

2.4.3. Does Neurostimulation Make a Difference: Can It Be Replaced by Ultrasound?

- In terms of success and safety, no clear evidence exists in the literature to support nerve stimulation as a superior approach over other traditional techniques. Some small studies have found it to be better than radiographic confirmation (obturator), and paresthesia (sciatic, axillary) and transarterial (axillary) approaches, while some have shown inferiority compared to techniques such as ultrasound (axillary, 3-in-1 femoral blocks).
- Nerve stimulation is appreciated for its objectivity and the fact that there is no need for patient reporting of paresthesias. However, it is still a variable and blind technique.
- One of the major concerns with nerve stimulation is illustrated by one study which found that up to 70% of patients had no motor response with stimulating currents of up to 1 mA despite patients experiencing paresthesias with positive verification of nerve proximity with ultrasound. This is partly due to interferences at the needle–tissue interface, as occurs with the presence of interstitial fluid or blood in the tissue. This may be resolved by using the recently introduced method utilizing nonconducting solutions (D5W; see Suggested Reading and References for this chapter).
- Studies using combined ultrasound and nerve stimulation guidance in peripheral nerve blockade have failed to demonstrate the value or added benefit of nerve stimulation to success. These studies have not been large enough to determine the safety of using ultrasound exclusively.
- Comparative studies between nerve stimulation and ultrasound have shown that ultrasound may be more beneficial during peripheral nerve blocks (e.g., 3-in-1 femoral blocks). Nevertheless, the studies have been small and variable in their power to provide best evidence.
- The main advantage of percutaneous electrode guidance to estimate the initial needle puncture site has been largely replaced by ultrasound imaging techniques.

- The inclusion of nerve stimulation during regional anesthesia procedures may be particularly helpful during training of ultrasound guidance in peripheral and neuraxial block techniques, the latter where ultrasound imaging is only able to provide indirect confirmation of needle and catheter placement (i.e., secondary to local anesthetic injection).

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