

# Peripheral Nerve Stimulation in the Practice of Brachial Plexus Anesthesia: A Review

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Success of plexus nerve block is dependent on the correct positioning of the local anesthetic solution near the desired nerves.<sup>1,2</sup> Throughout the history of regional anesthesia, elicitation of paresthesia has been a classical method to locate nerves, while mechanical aids, including radioscopy<sup>3</sup> and peripheral nerve stimulation (PNS),<sup>4,5</sup> have been promoted to facilitate close approximation of needle and nerve, theoretically increasing the corresponding success rate.<sup>2</sup>

Experience with electrical stimulation for locating nerves suggests it is beneficial in teaching regional anesthetic techniques to residents in training, performing difficult nerve blocks, or using novel approaches and smaller doses of local anesthetic.<sup>1,2,6</sup> Further, nerve stimulation can be used effectively for less cooperative patients and in anesthetized patients,<sup>7</sup> though the risk of neural injury remains present.<sup>8</sup>

Electrical stimulation facilitates the localization of nerves, and its use does not eliminate the need for basic technical knowledge: in effect, knowledge of the anatomy of the area to be blocked, the muscle innervation scheme, applied neurophysiology, and the pharmacology of the local anesthetic used. Consideration of these factors is important to evaluate the conflicting results in the PNS literature—results that in some cases are reportedly inferior to those of more classical methods, having only 2 series effec-

tively confirm that nerve stimulation affords an increased success rate with plexus block.<sup>9,10</sup>

For these reasons, the objective of our article is to review the applied neurophysiology and the principal features of the use of PNS in regional anesthesia.

## Basic Notions for Application of PNS in Regional Anesthesia

### Knowledge of Neurophysiology

Nerve signals are transmitted by action potentials that constitute fast changes in the membrane potential. In this sense, an excitable membrane depolarizes when the stimulation intensity reaches a minimum, or threshold, value.

Inducing an electric current through a nerve causes an excess ion flux through the axon membrane, thereby triggering an action potential. The characteristics of the pulse determine the resulting response. Generally, stimulation is performed using rectangular pulses, thereby avoiding prolonged currents. After stimulation, the membrane voltage does not change instantly, but rather in an exponential manner. If the stimulating pulse is short compared with the membrane time constant,\* then depolarization will not have reached a final or end value when current ceases.

Refractory periods also impact nerve stimulation. Nerve fibers possess a refractory period during which excitation is either more difficult than under resting conditions or is not possible at all: in the first stage, when the membrane is still depolarized, the refractory period is said to be “absolute” (with a duration of 1/2,500 seconds for large myelinated fibers), while in the second stage, lasting 1/4 to 1/2 the length of the preceding stage, the refractory status is only “relative.” This relative refractory period cor-

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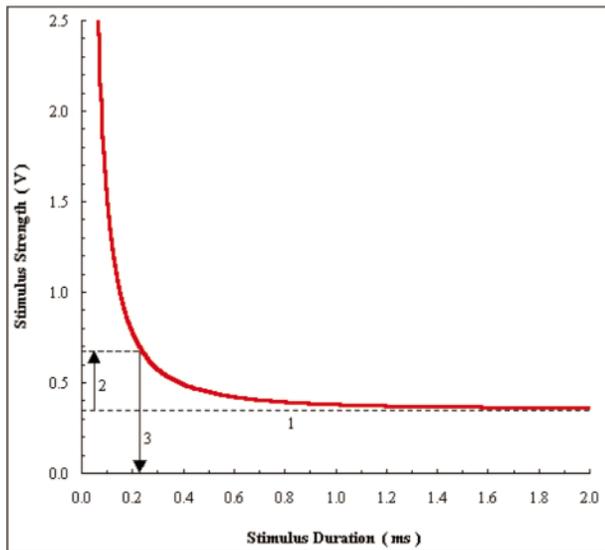
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\*The membrane time constant is a time constant relevant for determining the properties of the cell. This constant represents the time that it takes to charge up the membrane capacitance, and will also affect the generation of a postsynaptic potential. The membrane time constant of the neurons is 10 ms.

responds to a condition of partial inactivation of the sodium channels combined with extensive opening of the potassium channels, creating a hyperpolarized state in which nerve fiber stimulation is more difficult than under resting potential conditions. This intensity/duration proportionality and its correlation to excitability are best expressed in the form of a curve showing the current intensity sufficient to stimulate a cell or nerve as a function of pulse duration<sup>11</sup> (Fig 1).

The rheobase is the threshold intensity required for a sufficiently prolonged constant current to allow the membrane potential to reach a stable level. Chronaxie is, in turn, the minimum current duration required to produce a stimulation intensity twice that of the rheobase. Chronaxie is used to express the relative excitabilities of different tissues: Type A fibers: 0.1 to 0.2 ms; smaller myelinated fibers: 0.3 ms; unmyelinated fibers: 0.5 ms.

Theoretically, it may be possible to stimulate A $\alpha$  motor fibers without stimulation of the smaller A $\delta$  and C fibers that transmit pain. Thus, we may be able to stimulate and/or locate mixed nerves through observation of muscle contraction without causing patient discomfort. On the other hand, a



**Fig 1.** The curve showing the current intensity proportionality. The following steps are followed to determine rheobase and chronaxie. Step 1: Determine the rheobase, which is the foundation, or minimum, current (stimulus strength) that will produce a response. This is the voltage to which the Strength-Duration curve asymptotes. In the example shown, this value is 0.35 V. Step 2: Calculate  $2 \times$  rheobase ( $= 0.7$  V in the example shown). Step 3: Determine chronaxie, which is the stimulus duration that gives a response when the nerve is stimulated at twice the rheobase strength. In the example above, the chronaxie is 0.22 ms.

number of physiological factors have been identified that alter excitable cell membrane function, e.g., pregnancy. This is as a function of increased progesterone plasma levels.

The polarity of the electric stimulus during stimulation is also important, since the nerve fiber is more easily stimulated by the negative electrode, or cathode, being attached to the needle. On the other hand, if the positive electrode (or anode) is attached to the needle, the nerve fibers become more resistant to excitation than normal. At the anode, the displacement of positive charge toward the exterior of the membrane increases the voltage across it. This produces a state of hyperpolarization that diminishes fiber excitability. In contrast, negative current from the cathode reduces voltage on the outside of the membrane, situating it closer to the resting membrane potential; this in turn allows activation of the sodium channels more easily, thereby triggering an action potential.<sup>12,13</sup>

As pointed out above, the pulse characteristics of a stimulus are important in producing a response. The ideal electric parameters for comfortable stimulation include a frequency between 1 and 2 Hz and a duration of 1 to 2 ms. Stimulation intensity will be variable, as reflected by Coulomb's law:

$$E = K (Q/r^2),$$

where  $E$  is the required stimulating current,  $K$  is a constant,  $Q$  is the minimum stimulating current, and  $r$  is the distance between the active electrode and nerve. As current is inversely proportional to the square of this distance, values greater than 8 mm would require such significant strength stimuli that systemic effects might result (50 mA for a distance of over 2 cm).

This explains the need to regulate distance as a function of the response obtained—a range of 0.5 to 3 k $\Omega$  (or an average of 1.5 k $\Omega$ ) being considered the resistance of the skin between the active and neutral electrodes on the skin surface, and 0.01 to 0.5 mA the minimum current capable of producing a stimulus. The electrical resistance of the human body varies from 1 to 10 k $\Omega$  for wet skin to about 25 k $\Omega$  (between surface electrodes), and from this value decreases upon penetrating the dermis to only 0.5 k $\Omega$ . The energy source used should have an internal resistance greater than that of the human body (1 k $\Omega$ ), to avoid being affected by a variety of confounding variables, including ineffective contact of the skin electrodes, in order to ensure a constant current. When the resistance increases considerably above this value (a common event), the current decreases in direct proportion to the increase; as a result, fluctuations in current are observed despite the generation of impulse by

so-called “constant current” stimulators. These changes are related not only to confounding variables, but also to battery status, wear, and voltage decrease. Consequently, it is important to precisely measure the current in each pulse, for current (in milliamperes) and not voltage (in volts) is the most important variable when stimulating nerves. In this context, for pulse widths less than 100 ms, we could consider the use of nanocoloumbs (nC) for the more precise quantification of the applied stimulus, because on the intensity-duration curve small changes in pulse width may dramatically affect the current needed to stimulate the nerve.

Minimal stimulating current values of less than 0.5 mA constitute one factor associated with a higher success rate in performing stimulation-assisted regional blocks. The statistical correlation between minimal stimulating current is significant for values less than 0.5 mA, compared with higher minimal stimulating current values, without relation to the type of block performed. Variation in minimal stimulating current has been studied as a function of patient age or the pathology involved: 120 nC is normal, as is 60 nC in children, and over 1,000 nC in diabetics.

### PNS Technique

The nerve stimulator device should be designed and identified for fitting to the negative electrode (cathode, in black), and positive electrode (anode, in red) positioned on the patient as neutral return electrode.

Although conventional needles without electric insulation can be used, the dominant practice is to use insulated needles. A variety of such needles are available; many joined the extension tubing to needles with different tip designs (atraumatic pencil point, blunt, short bevel, etc). Insulated needles allow a more precise localization of the nerve, produce stimulation through the needle shaft, and require less current. In the case of noninsulated needles, the current reaching the nerve remains more or less constant after the needle advances beyond the nerve, rather than diminishing as occurs in the same setting when insulated needles are used. This difference in electrical response must be taken into account when performing the technique.<sup>13</sup>

After inserting the needle through the skin, the plexus “search phase” begins at an intensity chosen based on the expected depth of the plexus (usually 2 mA or less). When a motor response to plexus stimulation is elicited, the “approach phase” is performed until the minimum intensity capable of causing muscle contraction in the territory innervated by the brachial plexus is produced. The final

intensity should be less than 0.5 mA to ensure a high success rate; however, stimulation intensities of 0.3 mA are advised to further improve success rates.<sup>13</sup> Following the approach phase of stimulation, the selected local anesthetic solution is administered (the “injection phase”). Needle immobilization ensures that the administered volume is deposited in proximity to the stimulated nerve trunk and, thus, close to the brachial plexus. The specific motor-evoked activity disappears after administering 1 to 2 mL of local anesthetic, and reappears on increasing the stimulation intensity. Finally, the “anesthesia phase” develops—the duration of which depends on the location of the stimulated plexus, the anesthetic used, the combined administration of drugs that modify the physicochemical characteristics of the local anesthetic (e.g., bicarbonate) or its intraneural diffusion (such as mucopolysaccharidase),<sup>14</sup> and the technique used. In this context, PNS technique reduces the latency time but in turn prolongs the performance time.<sup>15-17</sup> Following the anesthesia phase, the result obtained should be evaluated before starting the surgery.

### Motor Responses to the PNS Technique

PNS is based on the assessment of motor responses. Both the sensory and motor innervation are conducted together by the mixed nerves. The mixed nerves forming the plexus structure consist of myelinated (A $\delta$ ) fibers where the different axons group randomly to form nerve fascicles. These fascicles comprise groups of axons with a common trajectory and which determine a common action (i.e., they are responsible for specific motor innervation). The clinical implication of this is that PNS yields a motor response dependent on the specific motor innervation of the fascicle or group of fascicles closest to the stimulus. This explains why multiple and varied motor responses are observed after stimulating the same trunk or nerve.

Other anatomy of importance for understanding the possible responses to PNS is the configuration of the actual plexus. In this sense, the brachial plexus is made up of the anterior branches of the C5 to T1 spinal nerves. These anterior branches join to form the corresponding primary trunks—superior (C5-C6), middle (C7), and inferior (C8-T1). In the periclavicular zone, the 3 trunks split into an anterior and a posterior division. The latter in turn regroup to form the secondary trunks at the infraclavicular level. It is in the anterior and posterior divisions of the plexus where nerve separation takes place to innervate the anterior (or flexor) muscles of the upper extremity (anterior divisions and anterolat-

eral and anteromedial secondary trunks) and its posterior (or extensor) muscles (posterior divisions and posterior secondary trunk).

Accordingly, motor response to PNS depends on the end-nerves—not on the metameres at infraclavicular and axillary levels—while the responses observed when performing interscalene and supraclavicular anesthetic techniques exhibit metameric characteristics. This is why PNS requires both knowledge of the motor responses dependent on the end-nerves and the capacity to identify metameric responses.

Lastly, satisfactory PNS results require the identification of responses distal to the stimulation site, taking care to not regard as positive those motor responses that could be attributable to direct muscle stimulation or to the stimulation of collateral nerves originating in the different zones of the brachial plexus.

Table 1 shows some of the upper extremity innervation pathways and the main motor responses elicited when performing brachial plexus block.<sup>18</sup> The aim of PNS is to elicit muscle contraction in one or more of the territories innervated by the nerves to be blocked.<sup>19</sup> In the case of the brachial plexus at axillary level, the typical response is elicited at wrist level or in the fingers. Thus, specific stimulation of the ulnar nerve produces lateral movements of the wrist, as well as flexion of the fourth and fifth fingers, and adduction of the thumb when deliver-

ing increased intensities. Median nerve stimulation produces palm flexion and opposition of the thumb, as well as pronation of the hand. Radial nerve stimulation causes extension of the elbow and/or wrist and of the fingers, while musculocutaneous nerve stimulation triggers flexion of the forearm upon the arm. If an infraclavicular approach is adopted, the plexus is usually localized at a high axilla level; as a result, the responses observed exhibit a distribution similar to that of the end-nerves. At this level, a motor response of the musculocutaneous nerve is acceptable for localization since it has not emerged from the brachial plexus. However, motor responses over the shoulder should be regarded as incorrect, since they can be induced by the stimulation of collateral nerves originating in the secondary trunks and which innervate the musculature of the axillary wall region. If a supraclavicular approach is adopted, the plexus is located at division or primary trunk level; as a result, the response elicited may exhibit end-nerve (when stimulus affects the divisions) or metameric characteristics (when stimulus affects the trunks). The responses observed are usually attributable to the uppermost trunks (superior and middle); consequently, the typical motor responses are prono-supination, flexion of the forearm, and carpal flexion-extension. The motor response is to be expected at the wrist joint. If the interscalene technique is performed, the plexus is located at trunk and/or anterior spinal

**Table 1. Upper Extremity Neural Innervation Pathways**

Muscle	Movement	Root	Trunk	Division	Cord	Peripheral Nerve
Spinal nerve origin						
Rhomboid major/minor		C5				Dorsal scapular
Serratus anterior		C5-C6				Long thoracic
Trunk origin						
Supraspinatus-infraspinosus		C5-C6	U			Suprascapular
Trunk origin						
Pectoralis major		C5-C6-C7	U/M	A	Lat	Lateral pectoral
Pectoralis major/minor		C8-T1	L	A	Med	Medial pectoral
Latissimus dorsi		C6-C7-C8	U/M	P	Post	Thoracodorsal
Teres major		C5-C6-C7	U/M	P	Post	Lower subscapular
Peripheral nerve branch origin						
Biceps brachii	Forearm flexion and supination	C5-C6	U	A	Lat	Musculocutaneous
Deltoid	Arm abduction	C5-C6	U	P	Post	Axillary
Triceps	Forearm extension	C7-C8	M/L	P	Post	Radial
Anconeus	Thumb opposition	C7-C8	M/L	P	Post	Radial
Brachioradialis	Forearm supination	C5-C6	U	P	Post	Radial
Extensor carpi radialis	Carpal extension	C6-C7	U/M	P	Post	Radial
Extensor digitorum	Fingers extension	C7-C8	M/L	P	Post	Radial
Extensor indicis			M/L	P	Post	Radial
Pronator teres	Forearm pronation	C6-C7	M/L	A	Lat	Median
Flexor carpi radialis	Carpal flexion	C6-C7	U/M/L	A	Lat/Med	Median
Pronator quadratus	Forearm pronation	C8-T1	L	A	Med	Median
Opponens pollicis	Thumb opposition	C8-T1	L	A	Med	Median
Flexor carpi ulnaris	Cubital-carpal flexion-lateralization	C7-C8-T1	M/L	A	Lat/Med	Ulnar
Flexor digitorum profundus (III-IV)	Fingers flexion (III-IV)	C7-C8-T1	M/L	A	Lat/Med	Ulnar
Flexor digitorum profundus (I-II)	Fingers flexion (I-II)	C7-C8-T1	M/L	A	Lat/Med	Median

Modified from Dumitru.<sup>18</sup>

nerve branch level; as a result, the response elicited is clearly metameric. Due to the characteristics of the technique, the commonly observed movements are dependent on the more cephalad roots (C5–C6) or superior trunk, and thus correspond to shoulder (abduction) and elbow (flexion) movements. Typical motor responses of a specific nerve can also be induced.<sup>20–22</sup>

### Accumulated Evidence of Advantages of PNS

Using PNS in regional anesthesia has been postulated to increase the success rate of the technique and reduce the required dose of local anesthetic. Baranowski and Pither,<sup>23</sup> in a comparative study of paresthesia, the “click” sign, and PNS in anesthetizing the brachial plexus via an axillary technique, concluded that the isolated “click” is not an ideal localization method. These investigators obtained similar success rates with the other 2 methods and recommended PNS in view of its lesser risk of nerve damage, though this latter point is unproven.

In efforts to improve resident training,<sup>24</sup> many have introduced the PNS technique as the method of choice in brachial plexus anesthesia. The results obtained by the most recent studies are actually based on the use of specific techniques for the localization of the different branches of the brachial plexus.<sup>9,10,15,16</sup> On the other hand, Martin et al.,<sup>7</sup> using a localization technique for identifying several nerves at axillary level, observed no reduction in the local anesthetic requirements with PNS. Moreover, these multiple injection techniques require the localization of 3 or 4 nerves—which in turn demands increased experience and a longer performance time.<sup>16</sup> As a result, some have embraced the double-injection technique, where initially a response is sought from the median nerve, followed by injection of one-half of the calculated dose. Depending on the surgical zone involved, a response is sought from the radial or ulnar nerve, followed by injection of the remaining dose. In the hands of the investigators, the analgesia and motor block achieved are significantly better than when the single-injection technique was used.<sup>15</sup> Also, Fannelli et al.<sup>17</sup> analyzed 3,996 patients undergoing surgery under brachial or lumbar plexus block. The investigators concluded that the multiple-injection technique with PNS affords a success rate of over 90%, with a volume of local anesthetic of under 30 mL.

Additionally, PNS has led to the development of new approaches, the success of which specifically depends on correct positioning of the needle tip with respect to the nerve plexus. A good example is

the infraclavicular approach to the brachial plexus, which has been proposed in a variety of techniques, all based on PNS as the localization technique. Neuburger et al.<sup>25</sup> propose vertical puncture, which yields an 88% success rate, while Salazar and Espinosa<sup>26</sup> advocate a technical modification of the classical approach that affords a 95% success rate.

Finally, a classical subclavian perivascular approach to brachial plexus has been reviewed by Franco and Vieira,<sup>27</sup> using a nerve stimulator instead of paresthesia for localization, obtaining 97.2% success in a series of 1,001 consecutive blocks. Franco and Vieira emphasize the importance of the use of PNS at the site of injection with this technique, on which the plexus is reduced to its smallest components and the sheath is reduced to its smallest volume, explaining in great part the success obtained with this block.

### Conclusions

Plexus anesthesia theoretically offers the best clinical results when objective and atraumatic techniques for nerve localization produce success and morbidity rates in inverse proportion. Perhaps the best expression of such results is patient satisfaction with the technique. We believe PNS presently allows a high and predictable success rate, with minimal morbidity, a low cost, and easy availability in our anesthetic practices. The need to analyze outcome data remains, and it is our hope this review will stimulate research in this area of our practice.

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