

## Using the nerve stimulator for peripheral or plexus nerve blocks

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Conventional methodology for nerve location utilizes anatomical landmarks followed by invasive exploration with a needle to a suitable endpoint. An appropriate endpoint can be either anatomical in nature (e.g. transarterial technique) or functional (paresthesia or motor response to electrical stimulation). Ability to electrically stimulate a peripheral nerve or plexus depends upon many variables, including; 1) conductive area at the electrode, 2) electrical impedance, 3) electrode-to-nerve distance, 4) current flow (amperage), and 5) pulse duration. Electrode conductive area follows the equation  $R = \rho L/A$ , where  $R$ =electrical resistance,  $\rho$ = tissue resistivity,  $L$ =electrode-to-nerve distance, and  $A$ =electrode conductive area. Therefore resistance varies to the inverse of the electrode's conductive area. Tissue electrical impedance varies as a function of the tissue composition. In general, tissues with higher lipid content have higher impedances. Modern electrical nerve stimulators are designed to keep current constant, in spite of varying impedance. The electrode-to-nerve distance has the most influence on the ability to elicit a motor response to electrical stimulation. This is governed by Coulomb's law:  $E = K(Q/r^2)$  where  $E$ =required stimulating charge,  $K$ =constant,  $Q$ =minimal required stimulating current, and  $r$ =electrode-to-nerve distance. Therefore, ability to stimulate the nerve at low amperage (e.g. <0.5 mA), indicates an extremely close position to the nerve. Similarly, increasing current flow (amperage) increases the ability to stim-

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ulate the nerve at a distance. Increasing pulse duration increases the flow of electrons during a current pulse at any given amperage. Therefore, reducing pulse duration to very short times (e.g. 0.1 or 0.05 ms) diminishes current dispersion, requiring the needle tip to be extremely close to the nerve to elicit a motor response. The above parameters can be varied optimally to enhance successful nerve location and subsequent blockade. Unlike imaging modalities such as ultrasonography, electrical nerve stimulation depends upon nerve conduction. Similarly, percutaneous electrode guidance (PEG) makes use of the above variables to allow prelocation of the nerve by transcutaneous stimulation.

Key words: Nerve stimulator - Percutaneous electrode guidance - Amperage - Paresthesia - Motor response.

Conventionally, location of a nerve or neural plexus for local anesthetic blockade has involved searching for the nerve by invasive needle exploration. This sometimes requires multiple needle passes to elicit the sought-after response from the nerve, such as a paresthesia or motor response to electrical nerve stimulation. With appropriate technique, such responses constitute evidence

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that the tip of the block needle is in contact with, or very close to, the targeted nerve. When using electrical nerve stimulation to seek a motor response, a weak direct current (DC) electrical current is supplied to the block needle by an oscillating (square-wave) current generator (*i.e.*, a nerve stimulator). The current is pulsed, typically at a frequency ( $f$ ) of 1-2 Hz. A starting current amplitude (amperage) of 1-2 mA with a pulse duration of 0.1 to 0.2 ms is typically applied to the block needle, which is inserted through the skin and underlying tissues toward the targeted nerve. When approximate motor contractions, which correspond to the muscular innervation of the designated nerve occur, the current is slowly decreased in amperage while the needle is used to search for the nerve. Motor contractions that occur at low amperage (usually 0.2-0.5 mA) indicate that the needle tip is very close to or contacting the nerve. Injection can thus be made in the immediate vicinity of the nerve, the objective, resulting in anesthesia or analgesia, with a very high success rate.

Conventional methodology for nerve location therefore begins by identification of anatomical landmarks. These landmarks constitute an approximate starting point for invasive needle exploration. The endpoint of the needle search can be an anatomical endpoint (*e.g.* transarterial axillary block or ultrasonographic imaging) or a functional endpoint (*e.g.* sensory response to mechanical stimulation, *i.e.* paresthesia, or motor response to electrical nerve stimulation).

The problem with designated anatomical landmarks is that they are variable from patient to patient and do not always correlate with the location of the underlying nerve or neural plexus. In addition, landmark measurements are often complicated, requiring linear measurements with a ruler, bisecting lines, and frequently a "one size-fits all" philosophy. For many blocks, accepted descriptions of the technique include insertion of the block needle a number of centimeters from a designated palpable landmark, neglecting patient size or body habitus. Dexterity and delicate proprioception are often required to be successful at block place-

ment. Finally, searching with a sharp needle can pierce or damage vessels, nerves, or other underlying anatomical structures.

Transcutaneous electrical stimulation, by contrast to an imaging technique such as ultrasonography, utilizes a functional endpoint, a motor or sensory response to electrical stimulation of the underlying nerve. Transcutaneous electrical stimulation to elicit a motor response has been used to assist in determination of the optimal entry point for needle insertion, thereby narrowing the invasive search for the nerve with the needle. Ganta *et al.*<sup>1</sup> reported on the use of a modified electrocardiographic electrode of 0.5 cm diameter with adherent gel to assist in the performance of interscalene block. The electrode was coupled to a nerve stimulator and was "passed along the skin" to locate the optimal entry point for needle insertion. Urmeý<sup>2</sup> proposed the use of an exploring skin electrode on a theoretical basis to help find the interscalene groove in patients with difficult anatomy.

Use of transcutaneous stimulation to elicit a sensory response (paresthesia) to electrical nerve stimulation of a purely sensory nerve (the lateral femoral cutaneous nerve) was reported by Shannon *et al.*<sup>3</sup> These investigators used a handheld electrical nerve stimulator to elicit sensory paresthesias, following which they made measurements to determine the nerve's location and injected, based upon these measurements, to block the nerve. Similar to Ganta *et al.*, Shannon *et al.* used an electrode that was approximately 0.5 cm diameter.

Urmeý and Grossi recently described a technique called percutaneous electrode guidance (PEG) of the block needle.<sup>4</sup> PEG utilizes transcutaneous electrical stimulation to non invasively prelocate the desired nerve or neural plexus. By contrast to the above transcutaneous techniques, the PEG technique uses an unprecedented cylindrical transcutaneous electrode with a minute (less than 1 mm) metallic tip. The electrode is used to indent the skin and underlying subcutaneous tissues toward the nerve, thus decreasing the tissue electrical impedance as well as the distance to the targeted nerve or nerves. The electrode is electrically shielded and sterile.

This technique was recently improved and simplified, while maintaining the original concept.<sup>5</sup> The stimulator needle tip was used as both the cutaneous and invasive electrode by encasing the needle in a rounded plastic non conductive sterile encasement that converts the needle tip, itself, to a smooth cutaneous electrode. The needle can be extended through the encasement toward the targeted nerve.

### Scientific fundamentals underlying percutaneous electrode guidance

Ability to electrically stimulate peripheral nerves depends on several variables. These include 1) conductive area of the electrode, 2) electrical impedance, 3) electrode-to-nerve distance, 4) current flow (amperage), and 5) pulse duration. These are discussed below.

#### *Conductive area of the electrode*

Electrical resistance is related to the conductive area of the electrode by the following equation:  $R = \rho L/A$ , where  $R$ =electrical resistance,  $\rho$ =tissue resistivity,  $L$ =electrode to nerve distance,  $A$ =conductive area. Therefore, because of the inverse relationship between resistance and the electrode's conductive area, use of a microelectrode tip on a shielded block needle serves to maximize resistance outside of the micro-conductive area at the needle's tip, enhancing specificity of nerve location by electrical stimulation.

#### *Tissue electrical impedance*

Electrical impedance is a function of the electrical resistance, capacitance, and inductance of the biological tissues in the immediate area of the stimulating needle and nerve or nerves. The majority of electrical impedance in biological tissues is due to resistance. In general, with the exception of specialized conducting tissue, the higher the water/lipid ratio, the lower is the electrical impedance. Krasteva *et al.* modeled the complex impedances that exist in human tissues.<sup>6</sup> State of the art commercial nerve stimulators are constant current generators that deliver constant

current despite variations in electrical impedance as the needle is advanced.

#### *Electrode-to-nerve distance*

As the stimulating needle is used to search for the nerve, the needle electrode-to-nerve distance is changed. If impedance is constant, the electrical field between 2 electrodes is described by Coulomb's law below:

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

where  $E$ =required stimulating charge;  $K$ =constant;  $Q$ =minimal required stimulation charge;  $r$ =distance between electrodes.

This has been applied to describe the electrical field between the needle electrode and nerve.<sup>7</sup> Electrical charge therefore dissipates rapidly (to the inverse square of needle to nerve distance). Although this is a theoretical oversimplification, the inverse square relationship is the reason that local anesthetic injection, following ability to stimulate at very low amperage (*i.e.*  $\leq 0.5$  mA), translates to high rates of block success. It is also the reason that in clinical practice, small movements of the stimulating needle frequently cause complete disappearance of the elicited motor response.

This relationship can also be used to explain the observations of UrmeY and Stanton<sup>8</sup> or Choyce *et al.*<sup>9</sup> that mechanical paresthesia is not always associated with an ability to elicit a motor response to electrical stimulation at low amperage and conventional 0.1 ms pulse duration.

#### *Current flow (amperage)*

Increasing amperage allows stimulation of a nerve at greater distance by increasing the charge for a given pulse duration. As described by Coulomb's law above,  $E$ , the required stimulating charge varies with the inverse square of the needle-to-nerve distance. Conversely, motor response at  $\leq 0.5$  mA (at low pulse duration  $\leq 0.1$  ms) signifies close proximity of the needle's tip to nerve, since the required charge is directly proportional to current flow.

### *Electrical pulse duration*

Clinical use of small pulse durations (*e.g.* 0.1 or 0.05 ms) have increased the accuracy or specificity of nerve location for peripheral nerve blocks. This is because charge of a given pulse is proportional, theoretically, to the product of electrical current and pulse duration. Similar to what occurs with increase in amperage, increasing pulse duration increases the ability to stimulate the nerve at a distance because the total charge of the pulse increases. This has been shown recently by Hadzic, *et al.*<sup>10</sup> who found that increasing amperage was required to elicit motor response as pulse duration decreased. Higher pulse durations increase the sensitivity or range of being able to stimulate at increased distance from the nerve but stimulation is not as specific or accurate as with small pulse duration.

Clinically, increasing current flow (amperage) has conventionally been used to increase stimulation range, since it allows stimulation at a greater distance from the nerve. Similarly, increasing pulse duration increases sensitivity for successful nerve stimulation with the stimulator needle at distance, whereas specificity is enhanced by decreasing pulse duration to 0.1 ms or below.

Although, increased pulse duration results in stimulation of unmyelinated C fibers to a greater degree than myelinated A fibers, we have not observed increased discomfort clinically. In a study of axillary block using different pulse durations, Kociliniak-Nielson *et al.* found no significant difference in patient discomfort between 1 ms and 0.1 ms pulses at the same current flow.<sup>11</sup>

### **Principles of PEG**

The PEG concept acts to optimize the above variables in such a way as to make transcutaneous stimulation and therefore prelocation of the target-nerve or nerves possible at relatively low amperage (<5 mA). The use of a smooth-tipped electrode allows indentation of the skin without significant discomfort. Indentation of the skin acts to minimize distance to the nerve and to

decrease electrical impedance by compressing the underlying tissues, which increases electrical conductance.

By contrast to traditional needle tip location, where a very short pulse duration is desirable for precise location with the needle tip, cutaneous stimulation benefits from longer pulse durations (0.2-1 ms). Higher pulse duration allows for motor response at lower amperage. Indentation of the skin (in some cases several centimeters is necessary) brings the cutaneous electrode into fairly close proximity of the nerve or neural plexus. Since much of the locating is done by the probe, which indents the skin toward the nerve, the needle tip typically travels only a short distance to the nerve.

### *Initial clinical experience with the PEG technique*

Urmeý and Grossi<sup>4</sup> reported the first clinical cases of peripheral or plexus blocks utilizing the PEG technique. The authors used a cylindrical cutaneous electrode with a 1 mm diameter metallic conductive tip. After positioning the probe and indenting the skin over the target nerve, specific motor responses were sought. At the point of maximal motor response at minimal cutaneous probe amperage (2 Hz, 0.2 ms) the cutaneous stimulator was turned off and a standard commercial nerve stimulator needle (BBraun, Melsungen, Germany) was passed through the probe to the nerve.

This method was used in 7 patients. Since the nerves were prelocated with the cutaneous electrode, the needle was introduced in each case with beginning amperage of 0.5 mA (normally acceptable as an endpoint). In only one case was it necessary to increase the needle amperage above 0.5 mA. Targeted nerves were found easily within seconds of the start of indentation and exploration of the skin with the cutaneous electrode. Minimal transcutaneous stimulation current in mA correlated directly with the measured needle depth (beyond the probe tip). Maximal needle protrusion depth in these initial patients was 2 cm. Thus the technique is more useful for blocking superficial nerves or plexuses. These include 1) brachial plexus

block, 2) midhumeral block, 3) wrist block, 4) femoral nerve block, 5) popliteal fossa block and, 6) posterior tibial nerve block.

PEG is in its infancy and has tremendous potential to make peripheral nerve blocks less intimidating to the beginning practitioner. PEG may decrease time for block performance and increase safety of peripheral nerve blockade by decreasing the number of invasive needle passes. The probe has been successfully used to teach in workshop settings. Further clinical studies are certainly indicated.

### Riassunto

*Utilizzo dello stimolatore nervoso per i blocchi dei nervi periferici o dei plessi nervosi*

La tecnica convenzionale per la localizzazione dei nervi utilizza dei punti di repere anatomici a cui fa seguito l'esplorazione invasiva con un ago per raggiungere gli obiettivi prefissati. L'obiettivo prefissato può essere di tipo anatomico (ad esempio tecnica transarteriosa) o funzionale (ad esempio, parestesia o risposta motoria alla stimolazione elettrica).

Aspetti scientifici fondamentali per la localizzazione nervosa: la possibilità di stimolare elettricamente un nervo periferico o un plesso nervoso dipende da molte variabili, tra le quali 1) l'area conduttiva dell'elettrodo, 2) l'impedenza elettrica, 3) la distanza tra l'elettrodo e il nervo, 4) il flusso della corrente elettrica (amperaggio) e 5) la durata dell'impulso.

L'area conduttiva dell'elettrodo segue l'equazione  $R = \rho L/A$ , dove  $R$  è la resistenza elettrica,  $\rho$  è la resistività del tessuto,  $L$  la distanza tra elettrodo e nervo e  $A$  l'area conduttiva dell'elettrodo. Di conseguenza la resistenza varia in modo inversamente proporzionale all'area conduttiva dell'elettrodo.

L'impedenza elettrica del tessuto varia in funzione della sua composizione. In generale, i tessuti ad alto contenuto lipidico hanno un'alta impedenza. I moderni stimolatori elettrici nervosi sono concepiti per fornire una corrente costante invece che per variare le impedenze.

La distanza tra elettrodo e nervo è l'aspetto che influenza maggiormente la capacità di scatenare una risposta motoria a seguito di una stimolazione elettrica. Questo aspetto segue la legge di Coulomb:  $E = K(Q/r^2)$ , dove  $E$  rappresenta il carico stimolante necessario,  $K$  è una costante,  $Q$  è la quantità minima di corrente stimolante necessaria e  $r^2$  è la distanza tra elettrodo e nervo. Di conseguenza, la capacità di stimolare il nervo con un basso amperaggio (ad esempio  $<0,5$  mA) indica che l'elettrodo è posizionato molto vicino al nervo.

Similmente, aumentando il flusso della corrente

(amperaggio) aumenta la possibilità di stimolare a distanza un nervo.

L'aumento della durata dell'impulso aumenta il flusso di elettroni durante una pulsazione corrente ad ogni dato amperaggio. Di conseguenza, la riduzione della durata dell'impulso a periodi molto brevi (ad esempio 0,1 o 0,05 ms) diminuisce la dispersione della corrente, e richiede che la punta dell'ago sia estremamente vicina al nervo per poter evocare una risposta motoria.

I parametri sopra citati possono essere variati in modo da ottimizzare la localizzazione del nervo e il suo conseguente bloccaggio. Diversamente da tecniche che utilizzano immagini, quali l'ecografia, la stimolazione elettrica nervosa dipende dalla conduzione del nervo. Similmente, l'elettrodo percutaneo con guida (PEG) consente di utilizzare le variabili prima descritte per consentire una pre-localizzazione del nervo tramite una stimolazione transcutanea.

Parole chiave: Stimolazione nervosa - Elettrodi percutanei - Amperaggio - Parestesie - Risposta motoria.

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