

Electrical Nerve Localization

Effects of Cutaneous Electrode Placement and Duration of the Stimulus on Motor Response

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Background: Recommendations regarding the technical aspects of nerve stimulator-assisted nerve localization are conflicting. The objectives of this study were to determine whether the placement of the cutaneous electrode affects nerve stimulation and to determine the duration and intensity of an electrical stimulus that allows nerve stimulation with minimal discomfort.

Methods: Ten healthy volunteers underwent an interscalene and a femoral nerve block. After obtaining a clearly visible motor response of the biceps (interscalene) and quadriceps (femoral) muscles at the minimal current (0.1 ms, 2 Hz), the position of the cutaneous electrode was varied. Next, the duration of the stimulating current was set at 0.05, 0.1, 0.3, 0.5, or 1.0 ms, in random order. Intensity of the motor response and discomfort on stimulation were recorded.

Results: The minimal current at which a visible motor response was obtained was 0.32 ± 0.1 mA (0.23–0.38 mA) for the interscalene block and 0.29 ± 0.1 mA (0.15–0.4 mA) for the femoral block. Changing the position of the return electrodes did not result in any change in the grade of the motor response or in the current required to maintain it. Currents of longer duration caused discomfort and more forceful contraction at a lower current intensity as compared with currents of shorter duration ($P < 0.01$). When the current was adjusted to maintain the same visible motor response, there was no significant discomfort among studied current durations.

Conclusion: Site of placement of the cutaneous electrode is not important when constant current nerve stimulators are used during nerve localization in regional anesthesia. There is an inverse relation between the current required to obtain a visible motor response and current duration. Selecting a current duration between 0.05 and 1.0 ms to specifically stimulate sensory or motor components of a mixed nerve does not seem to be important in clinical practice.

NERVE stimulation using a low-intensity current has become a common practice for localizing peripheral nerves before injecting local anesthetic when initiating a peripheral nerve block. However, there are conflicting recommendations regarding some technical aspects of nerve stimulation.

The purpose of a cutaneous (return; positive) electrode is to complete the electrical circuit, and its placement on the patient's body may influence the current flow. Conse-

quently, most authors agree that the location of the cutaneous electrode is important for accurate nerve localization, but opinions vary regarding its optimal location. Some teach that the return electrode should be placed as close to the site of needle insertion as possible,^{1,2} whereas others suggest that it should be placed in an area remote from the block needle.³

Furthermore, the acceptability of nerve stimulation for identifying peripheral nerves in regional anesthesia is based on the ability to stimulate motor components of mixed nerves without exciting sensory components that may cause discomfort. It is thought that a current of short duration (e.g., ≤ 0.1 ms) selectively stimulates motor components^{3–9} of a mixed nerve, whereas a current of longer duration (e.g., 1.0 ms) elicits sensory responses (“electrical paresthesia”), which may be uncomfortable.^{10–14} For example, using a current of longer duration (e.g., 0.5–1.0 ms) has been recently recommended to selectively produce sensory stimulation, such as during localization of cutaneous nerves or surface “nerve mapping.”^{14–17} Accordingly, several manufacturers have recently introduced peripheral nerve stimulators that feature user-adjustable pulse duration of the stimulus to selectively stimulate different components of mixed.^{10,11} However, to date, no study has verified that adjustable pulse duration is useful in clinical practice.

Lastly, the optimal current intensity resulting in accurate localization of a nerve has been a topic of controversy.^{3,4,14–16} For example, stimulation at currents higher than 0.5 mA may result in block failure because the needle tip is distant from the nerve, whereas stimulation at currents lower than 0.2 mA theoretically may risk possible intraneuronal injection.¹⁶ Other authors suggest that a motor response with a current intensity between 1.0 and 0.5 mA is sufficient for accurate placement of the block needle,³ whereas some advise using a current of much lower intensity (0.5–0.1 mA).^{4,15} Others simply suggest stimulating with currents less than 0.75 mA^{16,18} or progressively reducing the current to as low as possible while still maintaining a motor response.¹⁴

The objectives of this study were to determine whether the placement of the cutaneous electrode affects nerve stimulation, to study the effects of polarity reversal on the ability to stimulate a nerve, and to determine the duration and intensity of an electrical stimulus that allows accurate nerve localization with minimal discomfort.

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Materials and Methods

The study was approved by the Institutional Review Board of St. Luke's-Roosevelt Hospital Center (New York, New York), and written informed consent was obtained from 10 healthy volunteers (6 men and 4 women). On the day of study, a 22-gauge intravenous catheter was placed in the contralateral upper extremity to be blocked. Standard monitors for surgical anesthesia, as recommended by the American Society of Anesthesiologists, were used. High-quality conductive adhesive electrodes (BioTac[®] Ultra 7305; Kendall-LTP, Chicopee, MA) were applied at six locations: right and left volar aspects of the wrist, right and left ankle below the medial malleolus, the abdomen just cephalad the umbilicus, and 5 cm distal to the site of needle insertion. The site of electrode placement was prepared by shaving, if needed, and the skin was cleansed with alcohol. A right interscalene and a right femoral nerve block were performed, in random order, on each volunteer. Usual surface landmarks for interscalene and femoral nerve blocks were determined on each volunteer and marked with a pen.^{19,20} Needle insertion sites were anesthetized using approximately 2 ml ropivacaine, 0.2%, through a 25-gauge needle. A calibrated nerve stimulator (Tracer III; LifeTech, Stafford, TX) was used to elicit a motor response.²¹

Optimal Placement of the Grounding Electrode

A 50-mm, 22-gauge insulated needle was inserted at the predetermined injection site, and a motor response (biceps muscle for the interscalene block or quadriceps femoris muscle for the femoral block) was obtained using a low-intensity current starting at 0.6 mA (0.1 ms). The current was decreased to the minimal current necessary to obtain a grade 2 motor response (according to the motor response gradation scale) and recorded.

The motor response gradation scale was as follows:

- 0 = motor response absent
- 1 = motor response felt by palpation only but not visualized
- 2 = motor response easily visualized but no movement of the extremity
- 3 = a pronounced motor response resulting in movement of the extremity
- 4 = an exaggerated motor response resulting in movement of the extremity against gravity
- 5. powerful muscle contractions resulting in violent movement of the extremity

The needle was then stabilized, and the nerve stimulator was turned off. The impedance between the block needle and each of the six cutaneous electrodes was determined using an impedance meter (Fluke DigiMeter 123; Everett, WA) and a 1-kHz reference current. A custom-made six-position hard-wired switch box with gold-plated contacts and a total internal resistance of 0.1 Ω or less (including connecting cables) allowed us to switch to any

of the six cutaneous electrodes as needed. Measurements were performed in random order by an engineer unaware of the electrode being studied. After impedance was measured, the nerve stimulator was turned on again.

At the minimal current required for a grade 2 motor response, the position of the cutaneous electrode was varied using the six-way switch box. The grade of motor response was recorded for each cutaneous electrode position by the anesthesiologist performing the block, who was blinded to the current intensity used and the position of the cutaneous electrode selected. Finally, with the cutaneous electrode on the ipsilateral limb, the polarity was reversed (positive to needle) and the current intensity (0.1 ms) required to obtain a grade 2 response was recorded and compared with the intensity to maintain the same grade response using accepted polarity orientation.

Effect of Stimulus Duration on Discomfort during Nerve Stimulation

With the reference electrode set on the ipsilateral limb, the duration of the stimulating current was set at 0.05, 0.1, 0.3, 0.5, or 1 ms, in random order. Discomfort, defined by a visual analog scale (VAS) score of 3 or greater (VAS 0–10) at the minimal current output required to maintain grade 2 motor response was recorded for each stimulus duration. The anesthesiologist evaluating the motor response grade was blinded to stimulus duration and current intensity.

Effect of Stimulus Intensity on Discomfort during Nerve Stimulation

With the reference electrode set on the ipsilateral limb and the corresponding muscle motor response at grade 2, the stimulating current was increased in steps of 0.1 mA until the volunteer reported a VAS score of at least 3.

At the conclusion of the experiment, the current intensity (at 0.1 ms) resulting in a grade 2 motor response was restored. After negative aspiration, 10 ml 2-chloroprocaine, 3%, was injected. Ten minutes after the injection, the presence of autonomic, sensory, and motor blockade were determined. Autonomic blockade was assessed by cold temperature test (alcohol swab on the skin). Sensory blockade was determined using the tip of a paper clip. Motor blockade was present if the volunteer was unable to elevate the arm and touch the examiner's finger with the hand (interscalene) or extend the leg at the knee joint (femoral). Volunteers were monitored until the interscalene and femoral blocks resolved.

Statistics

Power was estimated based on the difference in current intensity (milliamperes) required to obtain a grade 2 motor response between the highest (1.0 ms) and lowest (0.05 ms) current durations. The power to detect a difference in current intensity of 0.5 (SE = 0.1) at $\alpha = 0.001$ for paired analyses was approximately 99% using 10 study subjects.

Table 1. Impedances between the Block Needle and Each of the Six Surface Electrodes for Interscalene and Femoral Block

Surface Electrode Placement	Impedance, k Ω Needle–Skin	
	Interscalene	Femoral
Left leg	13.7 \pm 5.7	11.6 \pm 4.5
Right leg	13.4 \pm 6.2	10.8 \pm 6.0
Left arm	13.0 \pm 5.8	12.7 \pm 5.2
Right arm	12.1 \pm 5.0	10.9 \pm 3.0
Umbilicus	12.3 \pm 4.7	10.7 \pm 2.6
5 cm distal	11.4 \pm 4.4	10.4 \pm 2.5

Data are presented as mean \pm SD. Differences within a block type not significant.

Data are presented as mean \pm SD (continuous variables) or as number (%) (discrete variables). Impedances (kilohms), voltages (volts), current (milliamperes), and current duration (milliseconds) were compared by paired *t* tests. To assess whether any of the limb sites differed in impedances, one-way analyses of variance were performed with Bonferroni adjustment for multiple comparisons. Similarly, one-way analyses of variance were performed to assess whether intensity of minimal current intensity required for a grade 2 motor response and discomfort differed by current duration and electrode placement. Statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS for Windows, version 11.0, Chicago, IL, 2001). A *P* value of 0.05 or less was considered significant.

Results

The mean age (\pm SD), weight, and height of the volunteers were 35 \pm 7 yr, 69 \pm 8 kg, and 168 \pm 12 cm, respectively. The measured impedances between the needle and each of the six cutaneous electrodes did not differ significantly for a specific block type (table 1).

The minimal current (0.1 ms, 2 Hz) at which a grade 2

motor response was observed was 0.32 \pm 0.1 mA (range, 0.23–0.38 mA) for the interscalene and 0.29 \pm 0.1 mA (range, 0.15–0.4 mA) for the femoral block. A grade 2 motor response was obtained in only 1 volunteer (during femoral nerve stimulation) using a current of less than 0.2 mA. Switching the position of the return electrode among the six locations did not result in any change in the grade of motor response (motor response) or in the current required to maintain it. Of note, at this current level (\leq 0.4 mA), all volunteers were aware of muscle contractions, but none perceived the sensation as being uncomfortable (VAS score = 0).

Polarity had a profound influence on the current required to obtain a motor response. Significantly greater current was required to maintain a grade 2 motor response when the polarity was changed from negative to positive: 0.34 \pm 0.07 to 0.98 \pm 0.4 mA, respectively, for interscalene and 0.29 \pm 0.09 to 1.01 \pm 0.31 mA, respectively, for femoral (*P* < 0.001).

There was an inverse relation between the minimal current required to maintain a grade 2 motor response and current duration. Significantly greater current was required for a grade 2 motor response with currents of shorter duration (*P* < 0.01; fig. 1).

Currents of longer duration caused both a greater motor response and discomfort (VAS score = 3) at lower intensity as compared with currents of shorter duration (*P* < 0.01; fig. 2). However, when the current output (milliamperes) of the nerve stimulator was adjusted to maintain a grade 2 motor response, there was no difference in discomfort among the five current durations tested. At a grade 2 motor response, none of the volunteers had any discomfort, regardless of the duration of stimulus. For current duration of stimulus, increasing the current intensity to exaggerate the motor response from grade 2 to grades 4–5 caused discomfort in eight (80%) of the volunteers for both the interscalene and the femoral nerve blocks (fig. 2). Two volunteers did not find

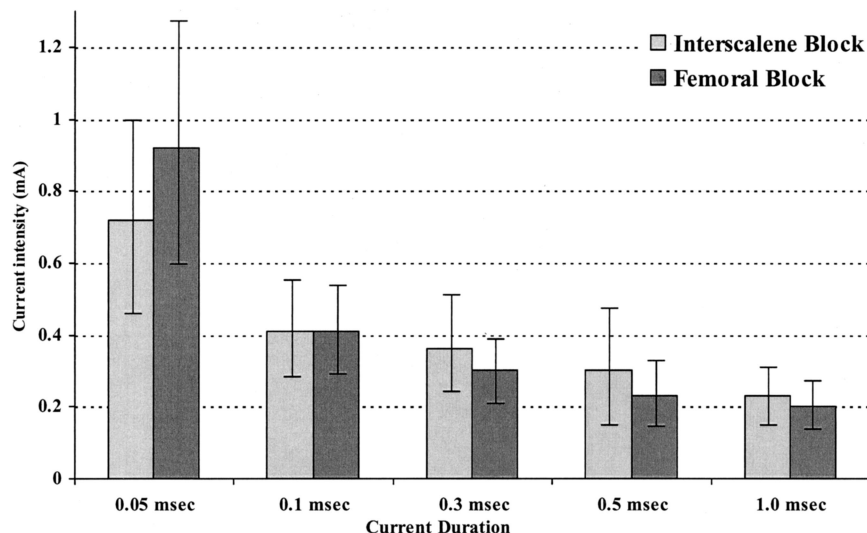
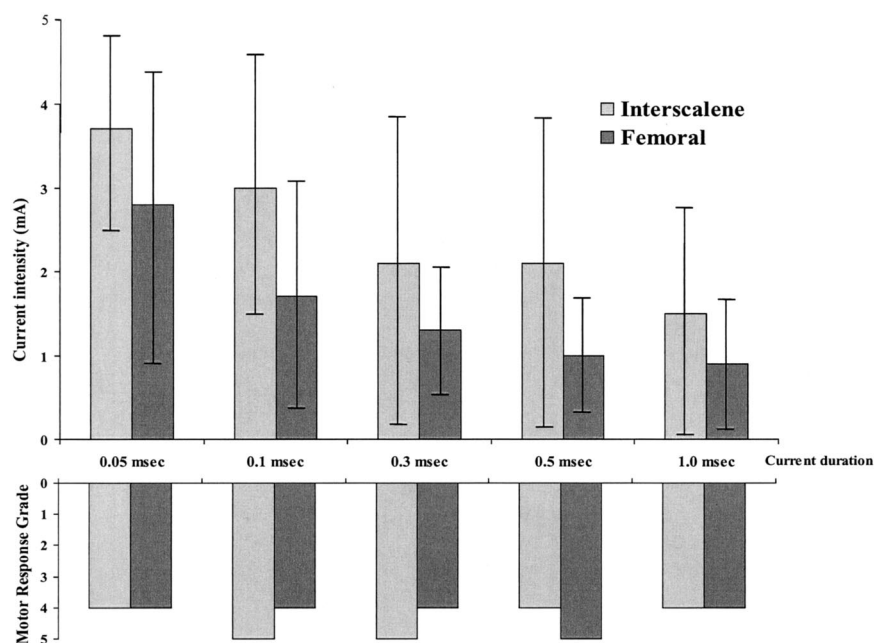
**Fig. 1. Current intensity at which minimal motor response was obtained.**

Fig. 2. Effects of the duration of the current (milliseconds) on the discomfort and motor response during nerve stimulation.



stimulation uncomfortable at any of the stimulus durations tested, even at a maximum current output of 5.0 mA.

At the conclusion of the study, all volunteers had evidence of interscalene and femoral blockade within 10 min of local anesthetic injection. This consisted of both sensory loss and motor weakness. All volunteers rated the local skin infiltration at the start of the block as the most uncomfortable part of the procedure.

Discussion

Electrical stimulation is commonly used to identify peripheral nerves when initiating nerve blocks. However, there is little information on the optimal technique of nerve stimulation. For example, the location of the cutaneous (return; positive) electrode may influence the ability to stimulate a nerve. However, recommendations as to where to place the cutaneous electrode vary widely. Some authors suggest that the cutaneous electrode should be placed near the site of the block,^{1,2} whereas others recommend placing it in an area distant from the block needle.³ Our data indicate that the site of the cutaneous electrode is not critical when using a constant current output nerve stimulator for nerve localization during interscalene brachial plexus and femoral nerve blockade. This finding is reassuring to clinicians treating a patient with a cast or local pathology because the ability to localize nerves is not affected by the inability to place the cutaneous electrode on the affected extremity. However, it is important to note that the nerve stimulator used in our study had constant current circuitry that automatically adjusted the voltage output to maintain the selected current intensity regardless of the impedance between the needle and cutaneous elec-

trode.²¹ Therefore, our findings may not be applicable to older stimulators without constant current technology.²¹

The optimal current with which to begin nerve localization without discomfort and the current intensity to reliably indicate when a needle is positioned sufficiently close to the nerve for block success is unknown. In our study, the minimal current required to obtain a grade 2 motor response was 0.32 ± 0.05 mA (range, 0.23–0.38 mA) for the brachial plexus and 0.29 ± 0.1 mA (range, 0.15–0.4 mA) for the femoral nerve when a duration of 0.1 ms was used. These results suggest that when performing interscalene brachial or femoral nerve blocks, it is probably not necessary to continue searching for a nerve response with currents of less than 0.2 mA at a stimulus duration of 0.1 ms because all volunteers in our study had successful blocks with as little as 10 ml local anesthetic.

It has been suggested that a current of short duration (≤ 0.1 ms) should be used for nerve stimulation in regional anesthesia to stimulate motor fibers of a mixed nerve (plexus) without stimulating sensory components and possibly causing discomfort to the patient.^{3,8,9} However, in our study, the duration of current did not have an effect on the degree of discomfort during nerve stimulation. In fact, increasing the current duration did not affect the level of discomfort during nerve localization so long as the motor response did not exceed grade 2. On the surface, this seemingly contradicts another finding of our study that a stimulus of longer duration causes discomfort (VAS score ≥ 3) at lower current intensity (fig. 2). This apparent contradiction can be explained by the fact that the total energy delivered to the nerve(s) is greater with stimuli of longer duration as described by the equation E (energy; nC) = I (current intensity; mA) \times t (duration of application; μ sec).⁸ For example, when set at a

current of 1.0 mA, a stimulus duration of 1.0 ms delivers 10 times more energy than a stimulus of 0.1 ms (1,000 nanocoulombs [nC] *vs.* 100 nC). Consequently, the greater energy delivered to the nerve results in a more forceful motor response, resulting in greater discomfort to the patient. These findings may not be applicable when attempting to localize neuropathic nerves because their excitability may be compromised by disease states.^{22,23}

Our results are in agreement with findings from our earlier clinical study demonstrating that low-current nerve stimulation does not result in significant discomfort to the patient.²⁴ Similarly, Koscielniak-Nielson *et al.*²⁵ found no difference in a patient's perception of electrical stimulation as being painful using "short" (0.1 ms) and "long" (0.3 ms) pulse durations. Nonetheless, some patients do experience discomfort during nerve localization with electrical stimulation.²⁶ As our results suggest, discomfort is more often elicited with a stimulating current of higher as compared with lower intensity. For example, at a commonly used stimulus duration of 0.1 ms, the median current at which discomfort (VAS = 3) occurred was 2.1 mA (range, 0.8–5.0 mA) for the interscalene and 1.7 mA (range, 0.35–4.0 mA) for the femoral nerve block. The discomfort level varied among the study subjects, and in two volunteers, discomfort (VAS score \geq 3) could not be elicited even at a maximum current output of 5 mA.

A reversal of polarity may occur in clinical practice when the cables to the nerve stimulator are erroneously connected. Similar to the results of Tulchinsky *et al.*,²⁷ our data indicate that a reversal of polarity from the usual negative to positive results in almost a threefold increase in the current required to elicit a motor response.

A potential limitation of our study was that subjects were exposed to multiple events and measurements during a relatively short period of time (30 min per block per volunteer). Although these occurred in random order, it is possible that this may have resulted in altered pain perception as the volunteers accommodated to nerve stimulation. It is also unknown whether multiple stimulations may have increased the threshold for a motor response. Finally, nerve stimulation in patients may be more uncomfortable because of local pathology (*e.g.*, fracture, arthritis) as compared with healthy volunteers.

In summary, under the conditions of our study, the site of placement of the cutaneous electrode is not important during nerve localization for peripheral nerve blocks. The duration of the stimulus can have a significant impact on the intensity of current required to stimulate the nerve as well as on the magnitude of the motor response obtained. Currents of greater intensity result in more pronounced motor responses and consequently may cause greater patient discomfort, regardless of the current pulse duration used. However, selecting a current duration (0.05–1.0 ms) specifically to preferentially stimulate sensory or motor components of a mixed nerve does not seem to be impor-

tant. Finally, special attention must be paid to polarity because an erroneous connection of cables may lead to errors in estimating the needle-nerve relation.

References

- Mulroy MF: Equipment, Regional Anesthesia. Edited by Mulroy MF. Philadelphia, Lippincott Williams & Wilkins, 2002, pp 51–63
- Katz J, Broadman LM, Rice LJ, Brown JW: Brachial plexus block, Atlas of Regional Anesthesia. Edited by Katz J, Broadman LM, Rice LJ, Brown JW. Norwalk, Connecticut, Appleton & Lange, 1994, pp 214–7
- Raj PP, De Andrés J, Grossi P, Banister R, Sala-Blanch X: Aids to localization of peripheral nerves, Textbook of Regional Anesthesia. Edited by Raj PP. New York, Churchill Livingstone, 2002, pp 251–84
- Brown DL: Local anesthetics and regional anesthesia equipment, Atlas of Regional Anesthesia. Edited by Brown DL. Philadelphia, Saunders, 1992, pp 3–11
- Kaiser H, Niesel HC, Hans V: Fundamentals and requirements of peripheral electric nerve stimulation: A contribution to the improvement of safety standards in regional anesthesia. *Reg Anesth* 1990; 13:143–7
- Kiernan MC, Lin CS, Murray AK, Bostock H: Clinical evaluation of excitability measures in sensory nerve. *Muscle Nerve* 2001; 24:883–92
- Panizza M, Nilsson J, Hallett M: Optimal stimulus duration for the H reflex. *Muscle Nerve* 1989; 12:576–9
- Pinnock CA, Fisher HB, Jones RP: Peripheral Nerve Blockade. Edited by Pinnock CA, Fisher HB, Jones RP. London, Churchill Livingstone, 1998, pp 9–13
- Pither CE, Raj PP, Ford DJ: The use of peripheral nerve stimulators for regional anesthesia: A review of experimental characteristics, technique, and clinical applications. *Reg Anesth* 1985; 10:49–58
- Stimuplex® HNS 11, Instruction manual [package insert]. Bethlehem, Pennsylvania: B. Braun Medical, Inc., 2001
- MultiStim PLEX Instruction Manual [package insert]. Gesingen, Germany: Pajunk, 2000
- Stone BA: Transcutaneous stimulation of the saphenous nerve to locate injection site. *Reg Anesth Pain Med* 2003; 28:153–4
- Urney WF, Grossi P: Percutaneous electrode guidance: A noninvasive technique for location of peripheral nerves to facilitate peripheral plexus or nerve block. *Reg Anesth Pain Med* 2002; 27:261–7
- Chelly J: Nerve stimulator, Peripheral Nerve Blocks: A Color Atlas. Edited by Chelly J. Philadelphia, Lippincott Williams & Wilkins, 1999, pp 7–10
- Jankovic D, Wells C: Brachial plexus, Regional Nerve Blocks, 2nd edition. Edited by Jankovic D, Wells C. Vienna, Blackwell Science Berlin, 2001, pp 58–86
- Jankowski CJ, Hebl JR, Stuart MJ, Rock MG, Pagnano MW, Beighley CM, Schroeder DR, Horlocker TT: A comparison of psoas compartment block and spinal and general anesthesia for outpatient knee arthroscopy. *Anesth Analg* 2003; 97:1003–9
- Selander D: Peripheral nerve injury after regional anesthesia, Complications of Regional Anesthesia, 1st edition. Edited by Finucane BT. Philadelphia, Churchill Livingstone, 1997, pp 105–15
- Tonidandel WT, Mayfield JB: Successful interscalene block with a nerve stimulator may also result after a pectoralis major motor response. *Reg Anesth Pain Med* 2002; 27:491–3
- Brown DL, Bridenbaugh LD: The upper extremity: somatic block, Neuroanesthesia and Management of Pain. Edited by Cousins MJ, Bridenbaugh PO. Philadelphia, Lippincott-Raven, 1988, pp 345–71
- Vloka JD, Hadzić A, Drobnik L, Ernest A, Reiss W, Thys DM: Anatomical landmarks for femoral nerve block: A comparison of four needle insertion sites. *Anesth Analg* 1999; 89:1467–70
- Hadzić A, Vloka JD, Hadzić A, Thys DM, Santos AC: Nerve stimulators used for peripheral nerve blocks vary in their electrical characteristics. *ANESTHESIOLOGY* 2003; 98:969–74
- Heckman JR: Excitability curve: A new technique for assessing human peripheral nerve excitability in vivo. *Neurology* 1972; 22:224–30
- Sites BD, Gallagher J, Sparks M: Ultrasound-guided popliteal block demonstrates an atypical motor response to nerve stimulation in two patients with diabetes mellitus. *Reg Anesth Pain Med* 2003; 28:479–82
- Kurc P, Hadzić A, Yufa M, Vloka JD, Brown AR, Visan A, Sanborn K, Santos AC: Painful paresthesia are infrequent during brachial plexus localization using low-current peripheral nerve stimulation. *Reg Anesth Pain Med* 2003; 28:380–3
- Koscielniak-Nielson J, Rassmussen H, Jepsen K: Effective impulse duration on patient's perception of electrical stimulation and block effectiveness during axillary block in unsedated ambulatory patients. *Reg Anesth Pain Med* 2001; 26:428–33
- Vloka JD, Hadzić A, Thys DM: Peripheral nerve stimulators for regional anesthesia can generate excessive voltage output with poor ground connection. *Anesth Analg* 2000; 91:1306–13
- Tulchinsky A, Weller RS, Rosenblum M, Gross JB: Nerve stimulator polarity and brachial plexus block. *Anesth Analg* 1993; 77:100–3