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Ultrasound *versus* peripheral nerve stimulator for peripheral nerve blockade: Pros and cons

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The use of ultrasound to perform peripheral nerve blocks is a relatively new technique that is rapidly gaining in popularity over the more traditional techniques of peripheral nerve stimulators and paresthesia. Lack of suitable ultrasound machines delayed the introduction of this modality into common practice until early 2000. Technological advances have resulted in the availability today of numerous ultrasound machines that are portable, decreasing in price although still not inexpensive, and have all the features that are necessary to perform ultrasound-guided regional anesthesia (USG-RA). It is interesting to note that the current debate regarding which technique is "better", ultrasound or PNS, is similar to the previous comparison between paresthesia and the PNS. The latter is a debate that has continued for decades and is still without a clear-cut answer. The objective of this lecture is to discuss the evidence for and against the use of USG-RA and to determine whether our current knowledge can support the use of US over that of the PNS.

The anesthesia literature has been inundated with articles, case reports and letters promoting, and occasionally questioning the use of ultrasound-guided regional anesthesia (USG-RA)(1). Proponents of this technique(2) argue that the use of ultrasound has the following advantages:

(1) Anatomical structures, for example nerves, blood vessels, the pleura, can be easily identified, as can unexpected anatomical variations and abnormalities.
(2) The insertion and placement of the block needle can be visualized in real time with the result that: (a) unintentional penetration of structures such as blood vessels and the pleura can be avoided and/or recognized, and (b) positioning and, if required, repositioning of the needle is performed under direct vision and in real time as opposed to blind redirection and repositioning of the needle with the PNS. This should result in decreased performance time and less patient discomfort.
(3) Penetration of a nerve sheath (e.g. the brachial plexus sheath) is in most cases easily visualized as indicated by initial indentation of the sheath followed by sudden recoil of the sheath during needle penetration.
(4) Injection of the local anesthetic solution is easily visualized, in real time as is the spread of the local anesthetic within the sheath and around the nerves. As a result, the controversy regarding the presence or absence of septa within the brachial plexus sheath becomes a non-issue as any nerve(s) that are not surrounded by local anesthetic during the initial injection can be identified. These nerves can then be blocked individually by simple repositioning the block needle and injecting an additional bolus of local anesthetic.
(5) Individual nerves can be identified and blocked anywhere along their pathway from core to periphery.
(6) Approaches that had fallen into disfavor due to potential complications have regained their popularity, i.e. the supraclavicular brachial plexus block.
(7) It has been suggested that peripheral nerve blocks can be safely performed in patients under general anesthesia with the use of ultrasound, however this issue is controversial.

As a result of the benefits described above, the time to perform the block as well as the onset time is decreased, the success rate is increased, the complication rate decreased, and, as a result, overall patient satisfaction is improved.

The primary argument advanced against the use of ultrasound is that the cost of the US machine cannot be justified as the benefits attributed to USG-RA over more traditional techniques have not materialized when performed by a skilled regional anesthesiologist. In addition, the lack of ultrasound machines at many institutions will place recently graduated anesthesia residents, trained only in the use of ultrasound and without PNS experience, at a disadvantage on entering

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the private practice[1]. This author, amongst many other regional anesthesiologists, totally disagrees particularly with the latter argument[2].

The objective of this lecture is to present the evidence in support of the use of ultrasound and to add a word of caution that its use does not guarantee a 100% success rate, nor is it free of complications[3,4]. The studies supporting the use of ultrasound have been arbitrarily divided into sections despite the fact that many of the studies address various benefits.

ANATOMY-RELATED BENEFITS

An issue frequently raised against the use of regional anesthesia in general is that, even in experienced hands, the success rate is rarely 100%. One of the reasons for this is that the anatomy of the human body is variable and these variations are unrecognizable during the performance of either a paresthesia or PNS technique, both of which depend on surface landmarks and blind needle insertion. Harry et al. demonstrated that the brachial plexus is situated between the anterior and middle scalene muscles in only 60% of cadavers[5]. In 34% of cadavers the C5 and/or C6 ventral roots penetrate the anterior scalene muscle. Kessler and Gray confirmed this variation by sonogram[6].

Besides these anatomical variants, US is useful in patients with difficult landmarks, for example the obese patient and scarring from previous surgery. It has also proved useful in facilitating the identification of landmarks for epidural anesthesia particularly in the obese and pregnant patient[7-9].

An interesting collateral benefit of the use of US is the occasional diagnosis of unexpected pathology unrelated to the nerve block. Sutin et al. reported the incidental finding of a previously undiagnosed femoral vein thrombosis in a patient with a fractured femur in whom an US-guided femoral nerve block was being performed[10].

TIME TO PERFORM THE BLOCK, DECREASED ONSET TIME AND INCREASED SUCCESS RATE

Orebaugh et al. compared the time taken by residents in a training program to perform various blocks (interscalene, axillary, femoral and popliteal) with either a PNS alone or a PNS aided by US[11]. The authors reported that US-aided blocks were faster to perform (median = 1.6 min *vs* 6.5 min, $P = < 0.001$), required less needle insertions (median = 2 vs 6, $P = < 0.001$), and resulted in fewer blood vessel punctures ($P = 0.03$).

Sites et al, compared the time to perform an axillary block utilizing a transarterial technique (TA) *versus* ultrasound (US) as well as the success rate[12]. The US group demonstrated a reduction in performance times vs. Group TA (7.9 ± 3.9 min *vs* 11.1 ± 5.7 min, P < 0.05) as well as a significantly greater success rate. The TA group sustained more failures defined as conversion to general anesthesia or the inability to localize the artery (TA eight patients (29%) *vs* Group US in which 0 patients required conversion to general anesthesia (0%) (P < 0.01).

In a prospective study, Williams et al assessed the quality, safety, and execution time of supraclavicular blocks of the brachial plexus using ultrasonic guidance and neurostimulation compared with a supraclavicular technique that used anatomical landmarks and neurostimulation[13]. At 30 min 95% of patients in the US group and 85% of patients in the NS group had a partial or complete sensory block of all nerve territories (P = 0.13) and 55% of patients in Group US and 65% of patients in Group NS had a complete block of all nerve territories (P = 0.25). Surgical anesthesia without supplementation was achieved in 85% of patients in Group US and 78% of patients in Group NS (P = 0.28). No patient in Group US and 8% of patients in Group NS required general anesthesia (P = 0.12). The quality of ulnar block was significantly inferior to the quality of block in other nerve territories in Group NS, but not in Group US; the quality of ulnar block was not significantly different between Groups NS and US. The block was performed in an average of 9.8 min in Group NS and 5.0 min in Group US (P = 0.0001). No major complication occurred in either group.

Soeding et al compared conventional “landmark-based” plexus anaesthesia to an ultrasound-guided approach in the performance of interscalene and axillary blocks[14]. The use of ultrasound significantly improved the onset and completeness of sensory (P = 0.011) and motor (P = 0.002) block. Ultrasound guidance also significantly reduced P = 0.012) the incidence of paraesthesia during the performance of the blocks.

Casati et al compared the time to onset of an axillary block utilizing a multiple injection technique with either US or a PNS[15]. The median (range) number of needle passes was 4 (3-8) in group US and 8 (5-13) in group PNS. The onset of sensory block was shorter in the US group (14 ± 6 min) than in the PNS group (18 ± 6 min) ($P = 0.01$) whereas no differences were observed in onset of motor block or readiness to surgery (28 ± 8 min in US group *versus* 28 ± min in PNS group).

Marhofer et al evaluated whether ultrasound facilitates the approach for 3-in-1 blocks[16]. Forty patients undergoing hip surgery after trauma were randomly assigned to either an ultrasound (US) or a nerve stimulator (NS) group. The onset of sensory blockade was significantly shorter in Group US compared with Group NS (US 16 ± 14 min, NS 27 ± 16 min, P < 0.05). The quality of the sensory block after injection of the local anesthetic was also significantly bet-

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ter in Group US compared with Group NS (US 15% ± 10% of initial value, NS 27% ± 14% of initial value, P < 0.05). A good analgesic effect was achieved in 95% of the patients in the US group and in 85% of the patients in the NS group. Incidental arterial puncture was observed in 3 patients, all in the NS group. They concluded that an US-guided approach for 3-in-1 block reduces the onset time, improves the quality of the sensory block and minimizes the risks associated with this regional anesthetic technique.

In a study in pediatric patients, Marhofer et al. reported that compared against the nerve stimulator, the use of US was found to be of benefit during the performance of infraclavicular blocks[17]. Forty children scheduled for arm and forearm surgery underwent infraclavicular brachial plexus blocks by either nerve stimulation or ultrasound visualization. Direct ultrasound visualization was successful in all cases and was associated with significant improvements when compared with the use of nerve stimulation: lower visual analogue scores during puncture (p = 0.03), shorter mean (median) sensory onset times (9 (5-15) min *vs* 15 (5-25) min, p < 0.001), longer sensory block durations (384 (280-480) min *vs* 310 (210-420) min, p < 0.001), and better sensory and motor block scores 10 min after block insertion. In addition, the pain associated with nerve stimulation due to muscle contractions at the time of insertion was eliminated.

Ultrasound guidance, with or without concomitant nerve stimulation, has also been shown to significantly improve the success rate of axillary brachial plexus block[18]. Patients undergoing elective hand surgery were randomly assigned to one of three groups. Axillary blocks were performed using three motor response endpoints in the nerve stimulator (NS) group, real-time ultrasound guidance in the ultrasound (US) group and combined ultrasound and nerve stimulation in the USNS group. A successful block was defined as complete sensory loss in the median, radial and ulnar nerve distribution by 30 min. Block success rate was higher in groups US and USNS (82.8% and 80.7%) than group NS (62.9%) (P = 0.01 and 0.03 respectively). Fewer patients in groups US and USNS required supplemental nerve blocks and/or general anesthesia. In addition, postoperatively, axillary bruising and pain were reported more frequently in group NS.

A similar benefit was reported by Sites et al comparing an axillary block performed by either a transarterial technique (Group TA) or an ultrasound-guided perivascular approach (Group US)[12]. Group TA sustained more failures defined as conversion to general anesthesia or the inability to localize the artery [Group TA eight patients (29%) vs. Group US in which 0 patients required conversion to general anesthesia (0%) P < 0.01]. Group US demonstrated a reduction in performance times vs Group TA (7.9 ± 3.9 min *vs* 11.1 ± 5.7 min, P < 0.05). An additional safety feature is associated with the ability to achieve a successful block with a reduced volume of local anesthetic.

INCREASED SAFETY

USG-RA may increase the safety of regional anesthesia in a number of ways. Lack of the characteristic spread of local anesthetic on initiation of the injection should result in the immediate reassessment of correct needle placement as the needle may be intravascular or intraneural. Abnormal distribution of the local anesthetic implies that the needle is not correctly positioned either within the plexus sheath or in close-enough proximity to a peripheral nerve. Significantly smaller volumes of local anesthetic can be used as individual nerves can be identified and blocked individually.

Marhofer et al evaluated whether US guidance for 3-in-1 blocks reduces the amount of local anesthetic required for a successful block compared to NS guidance[19]. Sixty patients undergoing hip surgery were randomly assigned to three groups of 20 patients each. In group A, the 3-in-1 block was performed using US guidance with 20 mL 0.5% bupivacaine. Group B received 20 mL 0.5% bupivacaine, and group C received 30 mL 0.5% bupivacaine during NS guidance. The overall success for the 3-in-1 block in group A was 95% and in groups B and C 80%. Onset time was significantly shorter in the US-guided group compared with both NS-guided groups (group A 13 ± 6 minutes; group B 27 ± 12 minutes; and group C 26 ± 13 minutes; P < .01 to groups B and C). Quality of sensory block was significantly better in group A (4% ± 5% of initial value) compared with groups B and C (group B 21% ± 11% of initial value, P < .01 to group A; group C 22% ± 19%, P < .01 to group A). The authors concluded that the amount of local anesthetic for 3-in-1 blocks can be reduced by using US guidance compared with the conventional NS-guided technique.

With a similar goal in mind, Casati et al. tested the hypothesis that ultrasound guidance may reduce the minimum effective anaesthetic volume (MEAV50) of ropivacaine 0.5% required to block the femoral nerve compared with nerve stimulation guidance[20]. Sixty patients undergoing knee arthroscopy were randomly allocated to receive a femoral nerve block with ropivacaine 0.5% using either nerve stimulation or ultrasound guidance. The volume of the injected solution was varied for consecutive patients based on an up-and-down staircase method according to the response of the previous patient. The initial volume was 12 mL. A double-blinded observer evaluated the occurrence of complete loss of pinprick sensation in the femoral nerve distribution, with concomitant block of the quadriceps muscle: positive or negative responses within 30 min after the injection determined a 3 mL decrease or increase for the next patient,

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respectively. The mean (sd) MEAV50 for femoral nerve block was 15 (4) mL (95% CI, 7-23 mL) in group US and 26 (4) mL (95% CI, 19-33 mL) in group NS (P = 0.002). The effective dose in 95% of cases (ED95) was 22 mL (95% CI, 13-36 mL) in group US, and 41 mL (95% CI, fs 24-66 mL) in group NS. Thus, US guidance provided a 42% reduction in the MEAV of ropivacaine 0.5% required to block the femoral nerve as compared with the nerve stimulation guidance.

The sensitivity of a paresthesia or PNS technique, as tools for nerve localization was studied by Perlas et al[21]. After needle-to-nerve contact was confirmed by ultrasonography, the patient was requested to report the presence of paresthesia, and a nerve stimulator as used to seek a motor response with a stimulating current of 0.5 mA or less. Paresthesia was found to be 38.2% sensitive and motor response was 74.5% sensitive (at 0.5 mA) for detection of needle-to-nerve contact. These findings suggest that needle-to-nerve contact may frequently occur without the subjective report of a paresthesia or an objective motor response. These findings add substance to the pro and con debate between the use of paresthesia versus the PNS, in which numerous studies have demonstrated that an unintentional paresthesia can be elicited without a muscle twitch (motor response) despite the use of a PNS. This in turn may result in inappropriate repositioning of the needle with the possibility of increased patient discomfort at best, and/or nerve injury at worst[22-25]. Utilizing ultrasound to perform supraclavicular blocks, Beach et al. demonstrated that in 13.5% of cases nerve stimulation failed to elicit a motor response despite correct needle location within the brachial plexus sheath[26].

LESS PATIENT DISCOMFORT

The fact that USG-RA can be performed more efficiently and with less manipulation of the needle suggests that patient discomfort during block performance should be reduced. Hu et al. addressed the issue of patient comfort during regional anesthesia. They included amongst their recommendations that the nerve stimulator technique should be preferred over the paresthesia technique[27]. In response, O'Sullivan, referring to studies by Marhofer, et al. stressed the benefits of ultrasound over the PNS in that uncomfortable muscle twitches are avoided with the US-guided technique[17,28,29]. Plunkett et al placed a supraclavicular continuous peripheral nerve block in a combat-injured soldier whose injuries precluded the use of a PNS[30].

Casati et al, in comparing an axillary brachial plexus block with either US or a PNS and multiple injection technique reported a median (range) number of needle passes of 4 (3-8) in the US group versus 8 (5-13) in group NS (P = 0.002)[15]. These results support the argument that patient discomfort is reduced by decreasing the number of needle insertions.

In comparing the efficacy of ultrasound, combined with nerve stimulation, to locate and block the sciatic nerve at the lateral midfemoral level compared to nerve stimulation alone, Domingo-Triado et al. reported that the success of sciatic nerve location at the first attempt was significantly more frequent in the US group than in the nerve stimulator group (76.6% *versus* 41.9%; P < 0.001)[31]. The quality of the sensory block and the tolerance to the pneumatic tourniquet were also significantly better in the US group (P < 0.01). They concluded that ultrasound combined with nerve stimulation improved the quality of the sensory block and the tolerance to the pneumatic tourniquet, and reduced the number of attempts to perform sciatic nerve blockade at the midfemoral level.

AVOIDANCE OF COMPLICATIONS

The avoidance of intraneural injections is a primary concern during the performance of regional anesthesia. Severe paresthesia and/or pain on injection, inability to inject or high resistance to injection[32,33] are all regarded as possible indicators of intraneural placement of the needle. Use of a PNS does not guarantee avoidance of nerve puncture[22,23,34]. Ultrasound has potentially added an additional layer of safety in that the needle as well as the nerves are easily visualized thus potentially reducing the incidence of nerve penetration by the needle. However, the occurrence of intraneural placement of the needle has not been eliminated. Correct needle placement within the plexus sheath and outside of the nerve results in the spread of local anesthetic that is characteristic and can be visualized in real time. On the other hand, a number of studies have reported on the image obtained during the initial phase of an intraneural injection i.e. expansion of the nerve with eventual rupture of the epineurium. Observation of the initial spread of 1 cc of local anesthetic can serve as an early warning sign of an intraneural injection[35-37].

In an interesting report by Bigeleisen, the incidence of apparent nerve puncture and intraneural injection of local anesthetic was prospectively studied in 26 patients undergoing ultrasound-guided axillary brachial plexus block[35]. Qualitative sensory and quantitative motor testing were performed before and 5 and 20 min after block placement. At a follow-up 6 months after the blocks, the patients were examined for any neurological deficit. In 22 out of 26 patients nerve puncture of at least one nerve occurred, and 21 of 26 patients had an intraneural injection of at least one nerve. In the entire cohort, 72 of a total of 104 nerves had intraneural injection. Sensory and motor testing before and 6 months after the nerve injections were unchanged. The author concludes that under the conditions of this study, puncturing of the peripheral nerves and apparent intraneu-

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ral injection during axillary plexus block did not lead to a neurologic injury.

REJUVENATION OF AN UNPOPULAR BLOCK

Although the supraclavicular approach to the brachial plexus has numerous advantages over the infraclavicular and axillary approaches, i.e. high success rate with a single injection and small volume technique as well as a rapid onset, its popularity declined based on the risk of a pneumothorax and injury to the subclavian artery. With the introduction of ultrasound, this approach has gained in popularity and is certainly this author's preference over the infraclavicular and axillary approaches for surgery below the shoulder. The plexus, artery, first rib and pleura are easily visualized as well as the course of the needle and the spread of local anesthetic. Williams et al[(13)] and Kapral et al[(38)] demonstrated the benefits of the use of ultrasound over conventional techniques, and Soares et al describe their technique of optimizing success rate[(39)].

THE "DISADVANTAGES" OF ULTRASOUND

The major criticism leveled against the use of ultrasound revolves around the cost and availability of ultrasound machines. This author favors the smaller, portable machines, however, even these machines are expensive with prices ranging between approximately $20,000 and $50,000 depending on the make, model and available options. In addition, the performance of USG-RA requires 2 individuals as the operator holds the probe in one hand and the needle in the other, therefore a second person is required to inject the local anesthetic (although Fredrickson et al reported successful continuous interscalene analgesia for ambulatory surgery in 300 patients in which a single operator placed nonstimulating catheters using a combination of ultrasound and nerve stimulation)[(40)]. These additional costs may be partially offset by an increase in the number of blocks performed (decreased time to perform the block plus shorter onset time)[(41)], a decrease in supplementation or conversion to general anesthesia (increased success rate), and a decrease in complications. An increase in success rate may result in further cost reduction due to less postoperative opioid-related side effects, better postoperative pain control and more rapid discharge from the PACU/ASU.

An issue that does need to be addressed involves the errors that occur due to inexperienced use of the ultrasound technique. Sites et al. videotaped six residents during the performance of 536 ultrasound-guided nerve blocks[(42)]. During the procedure 398 errors occurred of which failure to visualize the needle and unintentional probe movement were the commonest. In addition, 5 previously unrecognized "quality compromising patterns of behavior" were recognized. These included failure to recognize local anesthetic maldistribution as well as intramuscular location of the needle tip, failure to correlate the sidedness of the patient with that of the machine image, poor choice of needle insertion site and fatigue. These are issues that need to be vigorously addressed during training and simulation programs.

The use of USG-RA is still a relatively new technique with the result that numerous artifacts, both acoustic and anatomic exist that can result in prolonged procedure times, failed blocks, and patient injury[(43)]. Sites et al. define two major categories of imaging artifacts: (1) acoustic, i.e. errors in presentation due to incorrect use of machine controls such as the gain, depth, and frequency, and (2) anatomic, i.e. errors in interpretation (pitfall error) due to misinterpretation of an actual physical structure[(44,45)].

In conclusion, it is this author's opinion that the benefits of USG-RA far outweigh the few "disadvantages" described above. It should be stressed that the use of ultrasound does not preclude the use of a nerve stimulator as an additional resource to confirm correct needle placement, identify a specific nerve, or simply as an educational tool during the phase of conversion to ultrasound. The final objective is to provide safe, effective and efficient regional anesthesia with minimal discomfort to the patient.

REFERENCES

1. Hite BW, McCartney CJ. Pro/Con: Teaching residents with ultrasound hinders postgraduate practice of regional anesthesia. ASRA News 2007:6-8.
2. Brown AR, Abrahams MS, Atchabahian A. Pro/Con: Teaching residents with ultrasound hinders postgraduate practice of regional anesthesia - response (Letter). ASRA News 2007:7.
3. Hadzic A, Sala-Blanch X, Xu D. Ultrasound guidance may reduce but not eliminate complications of peripheral nerve blocks. Anesthesiology 2008;108: 557-558.
4. Zetlaoui PJ, Labbe JP, Benhamou D. Ultrasound guidance for axillary plexus block does not prevent intravascular injection. Anesthesiology 2008;108:761.
5. Harry WG, Bennett JD, Guha SC. Scalene muscles and the brachial plexus: anatomical variations and their clinical significance. Clin Anat 1997;10:250-252
6. Kessler J, Gray AT. Sonography of scalene muscle anomalies for brachial plexus block. Reg Anesth Pain Med 2007;32:172-3.
7. Arzola C, Davies S, Rofaeel A, Carvalho JC. Ultrasound using the transverse approach to the lumbar spine provides reliable landmarks for labor epidurals. Anesth Analg 2007;104:1188-1192, tables of contents.
8. Grau T, Leipold RW, Conradi R, Martin E, Motsch J. Efficacy of ultrasound imaging in obstetric epidural anesthesia. J Clin Anesth 2002;14:169-175.

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9. Grau T, Leipold RW, Fatehi S, Martin E, Motsch J. Real-time ultrasonic observation of combined spinal-epidural anaesthesia. Eur J Anaesthesiol 2004;21:25-31.
10. Sutin KM, Schneider C, Sandhu NS, Capan LM. Deep venous thrombosis revealed during ultrasound-guided femoral nerve block. Br J Anaesth 2005;94:247-248.
11. Orebaugh SL, Williams BA, Kentor ML. Ultrasound guidance with nerve stimulation reduces the time necessary for resident peripheral nerve blockade. Reg Anesth Pain Med 2007;32:448-454.
12. Sites BD, Beach ML, Spence BC, Wiley CW, Shiffrin J, Hartman GS, Gallagher JD. Ultrasound guidance improves the success rate of a perivascular axillary plexus block. Acta Anaesthesiol Scand 2006;50:678-684.
13. Williams SR, Chouinard P, Arcand G, Harris P, Ruel M, Boudreault D, Girard F. Ultrasound guidance speeds execution and improves the quality of supraclavicular block. Anesth Analg 2003;97:1518-1523.
14. Soeding PE, Sha S, Royse CE, Marks P, Hoy G, Royse AG. A randomized trial of ultrasound-guided brachial plexus anaesthesia in upper limb surgery. Anaesth Intensive Care 2005;33:719-725.
15. Casati A, Danelli G, Baciarello M, Corradi M, Leone S, Di Cianni S, Fanelli G. A prospective, randomized comparison between ultrasound and nerve stimulation guidance for multiple injection axillary brachial plexus block. Anesthesiology 2007;106:992-996.
16. Marhofer P, Schrogendorfer K, Koinig H, Kapral S, Weinstabl C, Mayer N. Ultrasonographic guidance improves sensory block and onset time of three-in-one blocks. Anesth Analg 1997; 85:854-857.
17. Marhofer P, Sitzwohl C, Greher M, Kapral S. Ultrasound guidance for infraclavicular brachial plexus anaesthesia in children. Anaesthesia 2004;59:642-646.
18. Chan VW, Perlas A, McCartney CJ, Brull R, Xu D, Abbas S. Ultrasound guidance improves success rate of axillary brachial plexus block. Can J Anaesth 2007;54:176-182.
19. Marhofer P, Schrogendorfer K, Wallner T, Koinig H, Mayer N, Kapral S. Ultrasonographic guidance reduces the amount of local anesthetic for 3-in-1 blocks. Reg Anesth Pain Med 1998;23:584-588.
20. Casati A, Baciarello M, Di Cianni S, Danelli G, De Marco G, Leone S, Rossi M, Fanelli G. Effects of ultrasound guidance on the minimum effective anaesthetic volume required to block the femoral nerve. Br J Anaesth 2007;98:823-827.
21. Perlas A, Niazi A, McCartney C, Chan V, Xu D, Abbas S. The sensitivity of motor response to nerve stimulation and paresthesia for nerve localization as evaluated by ultrasound. Reg Anesth Pain Med 2006;31:445-450.
22. Choyce A, Chan VW, Middleton WJ, Knight PR, Peng P, McCartney CJ. What is the relationship between paresthesia and nerve stimulation for axillary brachial plexus block? Reg Anesth Pain Med 2001;26:100-104.
23. Urmey WF, Stanton J. Inability to consistently elicit a motor response following sensory paresthesia during interscalene block administration. Anesthesiology 2002;96:552-554.
24. Ben-David B, Chelly JE. Current channeling: a theory of nerve stimulator failure. Anesth Analg 2003;96:1531-1532.
25. Sauter AR, Dodgson MS, Stubhaug A, Cvancarova M, Klaastad O. Ultrasound controlled nerve stimulation in the elbow region: high currents and short distances needed to obtain motor responses. Acta Anaesthesiol Scand 2007;51:942-948.
26. Beach ML, Sites BD, Gallagher JD. Use of a nerve stimulator does not improve the efficacy of ultrasound-guided supraclavicular nerve blocks. J Clin Anesth 2006;18:580-584.
27. Hu P, Harmon D, Frizelle H. Patient comfort during regional anesthesia. J Clin Anesth 2007;19:67-74.
28. Marhofer P, Greher M, Kapral S. Ultrasound guidance in regional anaesthesia. Br J Anaesth 2005;94:7-17.
29. O'Sullivan MJ. Patient comfort in regional anesthesia. Anesth Analg 2008;106:349; author reply 349-350.
30. Plunkett AR, Brown DS, Rogers JM, Buckenmaier CC, 3rd. Supraclavicular continuous peripheral nerve block in a wounded soldier: when ultrasound is the only option. Br J Anaesth 2006;97:715-717.
31. Domingo-Triado V, Selfa S, Martinez F, Sanchez-Contreras D, Reche M, Tecles J, Crespo MT, Palanca JM, Moro B. Ultrasound guidance for lateral midfemoral sciatic nerve block: a prospective, comparative, randomized study. Anesth Analg 2007;104:1270-1274, tables of contents.
32. Hadzic A, Dilberovic F, Shah S, Kulenovic A, Kapur E, Zaciragic A, Cosovic E, Vuckovic I, Divanovic KA, Mornjakovic Z, Thys DM, Santos AC. Combination of intraneural injection and high injection pressure leads to fascicular injury and neurologic deficits in dogs. Reg Anesth Pain Med 2004;29:417-423.
33. Kapur E, Vuckovic I, Dilberovic F, Zaciragic A, Cosovic E, Divanovic KA, Mornjakovic Z, Babic M, Borgeat A, Thys DM, Hadzic A. Neurologic and histologic outcome after intraneural injections of lidocaine in canine sciatic nerves. Acta Anaesthesiol Scand 2007;51:101-107.
34. Sala-Blanch X, Pomes J, Matute P, Valls-Sole J, Carrera A, Tomas X, Garcia-Diez AI. Intraneural injection during anterior approach for sciatic nerve block. Anesthesiology 2004;101:1027-1030.
35. Bigeleisen PE. Nerve puncture and apparent intraneural injection during ultrasound-guided axillary block does not invariably result in neurologic injury. Anesthesiology 2006;105:779-783.
36. Russon K, Blanco R. Accidental intraneural injection into the musculocutaneous nerve visualized with ultrasound. Anesth Analg 2007;105:1504-1505, table of contents.
37. Schafhalter-Zoppoth I, Zeitz ID, Gray AT. Inadvertent femoral nerve impalement and intraneural injection visualized by ultrasound. Anesth Analg 2004;99:627-628.
38. Kapral S, Krafft P, Eibenberger K, Fitzgerald R, Gosch M, Weinstabl C. Ultrasound-guided supraclavicular approach for regional anesthesia of the brachial plexus. Anesth Analg 1994;78:507-513.
39. Soares LG, Brull R, Lai J, Chan VW. Eight ball, corner pocket: the optimal needle position for ultrasound-guided supraclavicular block. Reg Anesth Pain Med 2007;32:94-95.
40. Fredrickson MJ, Ball CM, Dalgleish AJ. Successful continuous interscalene analgesia for ambulatory shoulder surgery in a private practice setting. Reg Anesth Pain Med 2008;33:122-128.
41. Sandhu NS, Sidhu DS, Capan LM. The cost comparison of infraclavicular brachial plexus block by nerve stimulator and ultrasound guidance. Anesth Analg 2004;98:267-268.
42. Sites BD, Spence BC, Gallagher JD, Wiley CW, Bertrand ML, Blike GT. Characterizing novice behavior associated with learning ultrasound-guided peripheral regional anesthesia. Reg Anesth Pain Med 2007;32:107-115.
43. Sites BD, Spence BC, Gallagher J, Beach ML, Antonakakis JG, Sites VR, Hartman GS. Regional anesthesia meets ultrasound: a specialty in transition. Acta Anaesthesiol Scand 2008;52:456-466.
44. Sites BD, Brull R, Chan VW, Spence BC, Gallagher J, Beach ML, Sites VR, Abbas S, Hartman GS. Artifacts and pitfall errors associated with ultrasound-guided regional anesthesia. Part II: a pictorial approach to understanding and avoidance. Reg Anesth Pain Med 2007;32:419-433.
45. Sites BD, Brull R, Chan VW, Spence BC, Gallagher J, Beach ML, Sites VR, Hartman GS. Artifacts and pitfall errors associated with ultrasound-guided regional anesthesia. Part I: understanding the basic principles of ultrasound physics and machine operations. Reg Anesth Pain Med 2007;32:412-418.

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