SPECIAL ARTICLE

Minimum anesthetic volume in regional anesthesia by using ultrasound-guidance

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Abstract The ultrasound guidance in regional anesthesia ensures the visualization of needle placement and the spread of Local Anesthetics.

Over the past few years there was a substantial interest in determining the Minimum Effective Anesthetic Volume necessary to accomplish surgical anesthesia. The precise and real-time visualization of Local Anesthetics spread under ultrasound guidance block may represent the best requisite for reducing Local Anesthetics dose and Local Anesthetics-related effects.

We will report a series of studies that have demonstrated the efficacy of ultrasound guidance blocks to reduce Local Anesthetics and obtain surgical anesthesia as compared to block performed under blind or electrical nerve stimulation technique.

Unfortunately, the results of studies are widely divergent and not seem to indicate a dose considered effective, for each block, in a definitive way; but it is true that, through the use of ultrasound guidance, it is possible to reduce the dose of anesthetic in the performance of anesthetic blocks.

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Volume mínimo de anestésico em anestesia regional guiada por ultrassom

Resumo O uso de ultrassom em anestesia regional permite visualizar a colocação da agulha e a propagação dos anestésicos locais.

Nos últimos anos houve um grande interesse em determinar o volume mínimo eficaz de anestésico necessário para fazer a anestesia cirúrgica. A visualização precisa e em tempo real da difusão dos anestésicos locais com o uso de ultrassom pode ser o melhor requisito para reduzir a dose e os efeitos relacionados aos anestésicos locais.

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Introduction

When traditional block techniques are used, the total amount of Local Anesthetics (LA) injected is often too close to the threshold dose of adverse/toxic reactions especially in case of accidental venous puncture.

A new frontier for regional anesthesia is offered by the possibility to perform nerve blocks under ultrasound guidance (USG), which allows identification of nerve structures. The LA dose needed in such cases is lower than the one normally used in a blind or an Electrical Nerve Stimulation (ENS) technique.1,2

Some recent studies have been designed to calculate the Minimum Effective Anesthetic Volume (MEAV) of LA needed to obtain a successful block. Others compared the MEAVs obtained by an ENS and by a USG technique.3-6

In fact, under the direct visualization of the nerve structures and the real-time control of the spread of LA, the reduction of the overall volume of anesthetics and the consequent overdose risk, is possible.

In this review the actual knowledge about MEAV is described and discussed.

Methods

All the randomized prospective clinical trials in which USG were used to achieve peripheral blocks with keywords in pubmed search "Minimal + Effective + Anesthetic + Volume" and, "Minimum + Effective + Anesthetic + Volume" were collected. Then the publications were divided by LA doses, by main study method and by site of block and were described (Table 1).

Results

Upper limb

For USG Axillary Brachial Plexus Block (ABPB), O’Donnell and Ilohom reported successful blocks with as little as 1 mL of 2% lidocaine with 1:200,000 epinephrine (2%LidoEpi) per nerve in a group of 11 consecutive patients submitted to hand surgery. The LA was administered by a perineural injection, circumferentially around each nerve. The block onset was of 10 min with a mean duration of 190 min.7 The same authors then used a "step-up/step-down" model with non-probability sequential dosing8 based on the outcome of the previous pilot study. The starting dose of 2% lido-e-pi was 4 mL per nerve. Block failure resulted in a dose increase of 0.5 mL; block success in a reduction of 0.5 mL until the achievement of a predetermined significant number of continuous successes. This model for LA dosage was then used in many other studies to determine the MEAV. 4 mL of LA was sufficient to obtain a successful block.9

Similarly, in another study aimed at evaluating the MEAV for a USG-ABPB10 in 19 patients undergoing hand or forearm surgery, the volume of lidocaine 1.5% with 1:200,000 epinephrine (1.5% lido-epi) needed to surround each nerve and to provide effective analgesia was of 3.42 mL for the radial, 2.75 mL for the median, 2.58 mL for the ulnar, and 2.3 mL for the musculocutaneous nerve. Although in everyday practice it is not easy to achieve such precise volumes – that were obtained by loading 1.5% lido-epi into a syringe driver and administrating through a bolus function at 600 mL/h10 – the possibility to obtain a surgical block with low volumes was confirmed.

González et al.11 have, recently, studied the minimum effective volume of lidocaine for double injection USG-ABPB. Fifty patients were included in the study. Using isotonic regression and bootstrap confidence interval (CI), the MEV90 was estimated to be 5.5 mL (95% CI, 3.0–6.7 mL) and 23.5 mL (95% CI, 23.1–23.9 mL) for the musculocutaneous and perivascular injection, respectively.

The question of whether USG can reduce the required volume of LA when compared with ENS for Interscalene Brachial Plexus Block (ISPB) was addressed in a randomized, double-blind, up/down sequential allocation study in 21 patients undergoing shoulder surgery.2 The MEAV of 0.5% ropivacaine was 0.9 mL in the USG group and 5.4 mL in the ENS group (p = 0.034) thus demonstrating that ultrasound not only reduces the LA volume, but also the number of attempts and postoperative pain when compared with ENS for ISPB.

In 2011, Gautier et al. investigated the MEAV for ISPB in 20 patients scheduled for shoulder surgery. Using the previously cited step-up/step-down method, the authors determined that 5 mL of 0.75% ropivacaine, or approximately 1.7 mL for each of the three trunks of the brachial plexus (superior, middle, and inferior) were sufficient to accomplish surgical anesthesia.12 Furthermore, the MEAV could contribute to reduce ISPB complications.

In 2008 Riazi et al.13 had examined the incidence of phrenic nerve palsy with a low-volume ISPB compared with a standard-volume technique both guided by ultrasound. They concluded that the use of low-volume USG-ISPB is associated with fewer respiratory and other complications.
Table 1  
Studies on Minimum Effective Anesthetic Volume evaluated for the review: methods, number of patients, type of block and surgery, type of local anesthetic, dosage and observed complications are described and compared.

<table>
<thead>
<tr>
<th>Methods</th>
<th>Comparison</th>
<th>Number of patients</th>
<th>Interventions</th>
<th>Surgery</th>
<th>Local anesthetic</th>
<th>LA doses (mL) or mL/sectional area (mL/mm²)</th>
<th>Complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>O’Donnel 2009</td>
<td>Dixon and Massey step-up/step down</td>
<td>11</td>
<td>Axillary brachial plexus block</td>
<td>Hand or forearm surgery</td>
<td>Lidocaine 2% + epinephrine 1:200,000</td>
<td>4 mL</td>
<td>None</td>
</tr>
<tr>
<td>Harper 2010</td>
<td>Pilot study</td>
<td>19</td>
<td>Axillary brachial plexus block</td>
<td>Hand or forearm surgery</td>
<td>Lidocaine 1.5% + epinephrine 1:200,000</td>
<td>2–4 mL to surround each nerve</td>
<td></td>
</tr>
<tr>
<td>González 2013</td>
<td>Prospective, randomized study</td>
<td>50</td>
<td>Double-injection axillary block</td>
<td>Hand or forearm surgery</td>
<td>Lidocaine 1.5% with epinephrine 5 µg/mL</td>
<td>MEAV₉₀: 5.5 mL and 23.5 mL</td>
<td>None</td>
</tr>
<tr>
<td>Gautier 2011</td>
<td>Prospective, randomized study</td>
<td>20</td>
<td>Interscalene brachial plexus block</td>
<td>Arthroscopic shoulder surgery</td>
<td>Ropivacaine 0.75%</td>
<td>5 mL; 1.7 mL for each of the three trunks</td>
<td></td>
</tr>
<tr>
<td>McNaught 2011</td>
<td>Randomized double-blind study</td>
<td>40</td>
<td>Interscalene brachial plexus block</td>
<td>Post-operative analgesia in shoulder surgery</td>
<td>Ropivacaine 0.5%</td>
<td>MEAV₉₀: 0.9 mL (US) vs 5.4 mL (NS)</td>
<td>No differences</td>
</tr>
<tr>
<td>Renes 2010</td>
<td>Prospective, observer and patient blinded trial</td>
<td>20</td>
<td>Interscalene brachial plexus block</td>
<td>Open shoulder surgery</td>
<td>Ropivacaine 0.75%</td>
<td>MEAV₉₅: 3.6 mL</td>
<td>Hemidiaphragmatic paresis: None 2 h after surgery; 55% follow-up 24 h</td>
</tr>
<tr>
<td>Duggan 2009</td>
<td>Dixon and Massey step-up/step down</td>
<td>21</td>
<td>Suprascapular block</td>
<td>Upper limb surgery</td>
<td>Lidocaine 2% + bupivacaine 0.5% with Epinephrine</td>
<td>MEAV₉₀: 23 mL MEAV₉₅: 42 mL</td>
<td></td>
</tr>
<tr>
<td>Tran 2011</td>
<td>Prospective, single blinded study</td>
<td>55</td>
<td>Infraclavicular block</td>
<td>Upper limb surgery</td>
<td>Lidocaine 1.5% + epinephrine 5 mcg/mL</td>
<td>MEAV₉₀: 35 mL</td>
<td>Vascular puncture, n (%): 1 (1.8)</td>
</tr>
<tr>
<td>Ponruch 2010</td>
<td>Prospective, randomized double blinded study</td>
<td>42</td>
<td>Median and ulnar nerve block</td>
<td>Carpal tunnel surgery</td>
<td>Mepivacaine 1.5%</td>
<td>Median/ulnar nerve: MEAV₉₀ 2 mL</td>
<td>None</td>
</tr>
<tr>
<td>Casati 2007</td>
<td>Prospective, randomized double blinded study</td>
<td>60</td>
<td>Femoral nerve block</td>
<td>Knee arthroscopic</td>
<td>Ropivacaine 0.5%</td>
<td>MEAV₉₀: 15 mL (USG) vs 26 mL (ENS) ED₉₀: 22 mL (USG) vs 41 mL (ENS)</td>
<td>None</td>
</tr>
<tr>
<td>Methods</td>
<td>Comparison</td>
<td>Number of patients</td>
<td>Interventions</td>
<td>Surgery</td>
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<td>LA doses (mL) or mL/sectional area (mL/mm²)</td>
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<tr>
<td>Marhofer 1998</td>
<td>US vs ENS guidance</td>
<td>60</td>
<td>3 in 1 block</td>
<td>Hip surgery</td>
<td>Bupivacaine 0.5%</td>
<td>20 mL</td>
<td>None</td>
</tr>
<tr>
<td>Latzke 2010</td>
<td>Dixon and Massey step-up/step down</td>
<td>20</td>
<td>Sciatic nerve block</td>
<td>Volunteers</td>
<td>Mepivacaine 1.5%</td>
<td>MEAV₅₀: 0.04 mL; MEAV₉₅: 0.08 mL; MEAV: 0.1 mL</td>
<td>None</td>
</tr>
<tr>
<td>Danelli 2009</td>
<td>Prospective, randomized, up-down sequential allocation, single blinded study</td>
<td>60</td>
<td>Sciatic nerve block</td>
<td>Knee arthroscopic</td>
<td>Mepivacaine 1.5%</td>
<td>MEAV₅₀: 12 mL (USG) vs 19 mL (ENS) MEAV: 14 mL (USG) vs 29 mL (ENS) mL/cross sectional area: MEAV₅₀: 0.08 mL/mm²; MEAV₉₅: 0.11 mL/mm²</td>
<td>None</td>
</tr>
<tr>
<td>Eichenberger 2009</td>
<td>Dixon and Massey step-up/step down</td>
<td>17</td>
<td>Ulnar nerve block</td>
<td>Healthy volunteers</td>
<td>Mepivacaine 1%</td>
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</table>
complications with no change in postoperative analgesia compared with the standard-volume technique. Renes et al. also confirmed these findings for hemidiaphragmatic paresis.

In a study conducted with an up-and-down design to determine the MEAV of 0.75% ropivacaine required to produce effective shoulder anesthesia for USG-ISPB at the C7 root level in 20 patients scheduled for elective open shoulder surgery under combined general anesthesia, pulmonary function was also investigated. MEAV50 and MEAV95 of the patients were 2.9 and 3.6 mL, respectively. Pulmonary function was unchanged until 2 h after surgery completion, but reduced 22 h after the start of a continuous infusion of ropivacaine 0.2%.15

The MEAV required for USG Supra-Clavicular Block (SCB) for surgical anesthesia using a 50:50 mixture of 2% lidocaine and 0.5% bupivacaine with epinephrine was studied in 21 adults undergoing elective upper limb surgery16: the MEAV95 was 42 mL and the authors deduced that the required volume of LA for USG-SCB does not seem to differ from the conventionally recommended volume using non-USG nerve localization techniques.

Subsequently Tran et al.17 showed that the MEAV90 of 1.5% lidocaine with 5 μg/mL epinephrine for double-injection USG-SCB was 32 mL.

The same authors adopted the "double bubble" sign in performing Infraclavicular Block ICB.10 This technique consists in exploring the axillary artery in short axis at the infraclavicular fossa; with an in-plane approach the needle is placed at the posterior pole of the axillary artery at around 6 o'clock. Then, a test volume is injected to ensure the correct placement of the tip of the needle, which should create a "double bubble" sign. With this method, Tran et al.18 found a MEAV90 of 35 mL for 1.5% lidocaine with 5 μg/mL epinephrine.

A 2009 study based on the ultrasound measured cross-sectional area calculated a mean volume of 0.7 mL (0.11 mL/mm of cross-sectional area) of 1% mepivacaine to block the ulnar nerve at the proximal forearm.19

Ponrouch et al.14 designed a randomized, double-blind controlled comparison between ENS and USG to estimate the MEAV of 1.5% mepivacaine in median nerve blocks. Twenty-one patients scheduled for carpal tunnel release were enrolled with a step-up/step-down study model. The authors found that USG provided a 50% reduction in the MEAV in comparison with ENS and that decreasing the LA volume can decrease sensory block duration but not the onset time.

Lower limb

Fewer studies were made to estimate the MEAV for lower limb blocks. Casati et al.4 tested the hypothesis that USG may reduce MEAV of 0.5% ropivacaine required to block the femoral nerve compared with ENS. Sixty patients undergoing knee arthroscopy were enrolled. The volume of the injected solution was regulated for consecutive patients based on an up-and-down staircase method according to the response of the previous patient. USG guidance provided a 42% reduction in the MEAV of 0.5% ropivacaine required to block the femoral nerve as compared with the ENS; MEAV50 was of 22 mL for the USG group and of 41 mL for the ENS group.

Enrolling a sample of 60 patients undergoing hip surgery following trauma Marhofer et al.20 demonstrated that USG can also reduce the amount of local anesthetic for the 3-in-1 block when compared with conventional ENS technique.

Latzke et al.21 conducted the first randomized, double-blinded volunteer study designed to evaluate the volume of LA for a sciatic nerve block using a step-up/step-down methodology. 20 volunteers were included. The effective dose of 1.5% mepivacaine for sciatic nerve block was calculated for 0.10 mL/mm² cross-sectional nerve area.

Danelli et al.22 tested the MEAV of 1.5% mepivacaine required to block the sciatic nerve with a subgluteal USG approach compared with ENS. For this purpose, 60 patients undergoing knee arthroscopy were randomly allocated to receive a sciatic nerve block with either USG (n = 30) or ENS (n = 30). Again the volume of 1.5% mepivacaine was varied for consecutive patients based on an up-and-down method, according to the response of the previous patient. Ultrasound provided a 37% reduction in the MEAV90 of 1.5% mepivacaine required to block the sciatic nerve compared with ENS. The MEAV90 was 14 mL in the USG group and 29 mL in the ENS group.

Discussion

Numerous studies emphasized the importance of USG in the management of peripheral nerve blocks.23-26

However, it is not yet clear whether the USG for nerve location is superior to other existing methods. In order to assess the advantages of USG peripheral nerve location, Walker et al. searched the relevant published trials, from year 1945 till year 2008, comparing USG peripheral nerve block with at least one other method of nerve location. 18 trials were included containing data from 1344 patients with most trials comparing USG with ENS. Meta-analysis was not performed due to the variety of blocks, techniques, and outcomes, and the review was based on the authors’ assessment of the trials. Walker et al.27 concluded that in experienced hands, ultrasound provides at least as good success rates as other methods of peripheral nerve location; it may also improve onset time and quality, reduce performance time and compication rates particularly vascular puncture and hematoma formation.

Furthermore, the skills required to perform successful ultrasound-guided axillary brachial plexus block can be learnt faster and lead to a higher final success rate compared to nerve stimulator-guided axillary brachial plexus block.28

On the other hand, the use of ultrasound enabled the direct visualization of LA spread around the nerve structures; this revolutionary real-time procedural assessment allowed the study of the correlation between the LA dosage and the efficacy of the peripheral nerve block.2,29 In this review we included the studies that investigated the MEAV for surgical anesthesia.3,5,7,9,21 We divided the studies by block type, briefly discussed each of them and summarized in Table 1 the results.

Unfortunately, the results of studies, conducted up to this moment, are widely divergent and not seem to indicate a dose considered effective, for each block, in a definitive
way. In fact, often, there are single center case histories and the number of cases is small; the methods of investigation are also different and anesthetic techniques are not standardized.

Conclusion

Through the use of ultrasound guidance, it is possible to reduce the dose of anesthetic in the performance of anesthetic blocks. In our opinion, the LA dose reduction may be a very relevant contribution the USG can offer to regional anesthesia.

However, more homogeneous studies should be performed to identify the MEAV for each kind of nerve block; techniques and drug administration should be standardized in order to reduce confounding factors so that reliable meta-analyses would be performed.

Conflicts of interest

The authors declare no conflicts of interest.

References