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SPECIAL ARTICLE

Minimum anesthetic volume in regional anesthesia by using ultrasound-guidance

Alessandro Di Filippo*, **Silvia Falsini**, **Chiara Adembri**

Department of Health Sciences, Section of Anesthesia, Intensive Care and Pain Therapy, University of Florence, Florence, Italy

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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.

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 in 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.

* Corresponding author.
E-mail: adifilippo@unifi.it (A. Di Filippo).

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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 Iohom 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 administrated 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 dosing[8] based on the outcome of the previous pilot study. The starting dose of 2% lido-epi 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-ABPB[10] 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 is it 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/h[10] – 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 (ISBPB) was addressed in a randomized, double-blind, up/down sequential allocation study in 21 patients undergoing shoulder surgery.[3] 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 ISBPB.

In 2011, Gautier et al. investigated the MEAV for ISBPB 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 ISBPB complications.

In 2008 Riazi et al.[13] had examined the incidence of phrenic nerve palsy with a low-volume ISBPB compared with a standard-volume technique both guided by ultrasound. They concluded that the use of low-volume USG-ISBPB is associated with fewer respiratory and other complications with no change in postoperative analgesia compared with the standard-volume technique. Renes et al.[14] 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. $MEAV_{50}$ and $MEAV_{95}$ 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 surgery[16]: the $MEAV_{95}$ 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 $MEAV_{90}$ 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.[18] 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 $MEAV_{90}$ 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.[4] 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.

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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.

	Methods	Comparison	Number of patients	Interventions	Surgery	Local anesthetic	LA doses (mL) or mL/sectional area (mL/mm^2)	Complications
O'Donnel 2009		Dixon and Massey step-up/step down	11	Axillary brachial plexus block	Hand or forearm surgery	Lidocaine 2% + epinephrine 1:200.000	4 mL	None
Harper 2010	Pilot study		19	Axillary brachial plexus block	Hand or forearm surgery	Lidocaine 1.5% + epinephrine 1:200,000	2–4 mL to surround each nerve	
González 2013	Prospective, randomized study	Dixon and Massey step-up/step down	50	Double-injection axillary block	Hand or forearm surgery	lidocaine 1.5% with epinephrine 5 µg/mL	$MEAV_{90}$: 5.5 mL and 23.5 mL	None
Gautier 2011	Prospective, randomized study	Dixon and Massey step-up/step down	20	Interscalene brachial plexus block	Arthroscopic shoulder surgery	Ropivacaine 0.75%	5 mL; 1.7 mL for each of the three trunks	
McNaught 2011	Randomized double-blind study	USG vs ENS guidance/Dixon and Massey step-up/step down	40	Interscalene brachial plexus block	Post-operative analgesia in shoulder surgery	Ropivacaine 0.5%	$MEAV_{50}$: 0.9 mL (US) vs 5.4 mL (NS)	No differences
Renes 2010	Prospective, observer and patient blinded trial	Dixon and Massey step-up/step down	20	Interscalene brachial plexus block	Open shoulder surgery	Ropivacaine 0.75%	$MEAV_{95}$: 3.6 mL	Hemidiaphragmatic paresis: None 2 h after surgery; 55% follow-up 24 h
Duggan 2009		Dixon and Massey step-up/step down	21	Supraclavicular block	Upper limb surgery	Lidocaine 2% + bupivacaine 0.5% with Epinephrine	$MEAV_{50}$: 23 mL $MEAV_{95}$: 42 mL	
Tran 2011	Prospective, single blinded study	Dixon and Massey step-up/step down	55	Infraclavicular block	Upper limb surgery	Lidocaine 1.5% + epinephrine 5 mcg/mL	$MEAV_{90}$: 35 mL	Vasculare puncture, *n* (%): 1 (1.8)
Ponrouch 2010	Prospective, randomized double blinded study	USG vs ENS guidance/Dixon and Massey step-up/step down	42	Median and ulnar nerve block	Carpal tunnel surgery	Mepivacaine 1.5%	Median/ulnar nerve: $MEAV_{50}$ 2 mL	None
Casati 2007	Prospective, randomized double blinded study	US vs ENS guidance	60	Femoral nerve block	Knee arthroscopic	Ropivacaine 0.5%	$MEAV_{50}$: 15 mL (USG) vs 26 mL (ENS) ED_{95}: 22 mL(USG) vs 41 mL (ENS)	None

Table 1 (*Continued*)

	Methods	Comparison	Number of patients	Interventions	Surgery	Local anesthetic	LA doses (mL) or mL/sectional area (mL/mm^2)	Complications
Marhofer 1998		US vs ENS guidance	60	3 in 1 block	Hip surgery	Bupivacaine 0.5%	20 mL	
Latzke 2010		Dixon and Massey step-up/step down	20	Sciatic nerve block	Volunteers	Mepivacaine 1.5%	$MEAV_{50}$: 0.04 mL; $MEAV_{95}$: 0.08 mL; MEAV: 0.1 mL	None
Danelli 2009	Prospective, randomized, up-down sequential allocation, single blinded study	US vs ENS guidance	60	Sciatic nerve block	Knee arthroscopic	Mepivacaine 1.5%	$MEAV_{50}$: 12 mL(USG) vs 19 mL(ENS) MEAV: 14 mL (USG) vs 29 mL (ENS)	None
Eichenberger 2009	Prospective, randomized double blinded study	Dixon and Massey step-up/step down	17	Ulnar nerve block	Healty volunteers	Mepivacaine 1%	mL/cross sectional area: $MEAV_{50}$: 0.08 mL/mm^2 $MEAV_{95}$: 0.11 mL/mm^2	

Lower limb

Fewer studies were made to estimate the MEAV for lower limb blocks.

Casati et al.[6] 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; $MEAV_{95}$ 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/mm^2 cross-sectional nerve area.

Danelli et al.[5] 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 $MEAV_{50}$ of 1.5% mepivacaine required to block the sciatic nerve compared with ENS. The $MEAV_{95}$ 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.[22–26]

However, it is not yet clear whether the USG for nerve location is superior over 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 complication 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.[1,2] In this review we included the studies that investigated the MEAV for surgical anesthesia.[3–7,9–21] 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 that they have no conflict of interest in writing this article.

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