Effects of ultrasound guidance on the minimum effective anaesthetic volume required to block the femoral nerve

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Background. We tested the hypothesis that ultrasound guidance may reduce the minimum effective anaesthetic volume (MEA V50) of ropivacaine 0.5% required to block the femoral nerve compared with nerve stimulation guidance.

Methods. After standard premedication and sciatic nerve block were given, 60 patients undergoing knee arthroscopy were randomly allocated to receive a femoral nerve block with ropivacaine 0.5% using either nerve stimulation (group NS, n=30) or ultrasound (group US, n=30) 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, respectively.

Results. The mean (SD) MEA V50 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) calculated with probit transformation and logistic regression analysis was 22 ml (95% CI, 13–36 ml) in group US, and 41 ml (95% CI, fs 24–66 ml) in group NS.

Conclusions. Ultrasound guidance provided a 42% reduction in the MEA V of ropivacaine 0.5% required to block the femoral nerve as compared with the nerve stimulation guidance.


Keywords: anaesthetic techniques, regional, femoral nerve block; anaesthetics local, ropivacaine; equipment, nerve stimulator, ultrasound

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The volume of local anaesthetic solution injected in the proximity of a peripheral nerve is a crucial factor improving the success rate and predictability of peripheral nerve blocks.1,2 On the other hand, the possibility of blocking major nerves with the smallest possible volume of local anaesthetic could add to the safety of peripheral nerve blocks,3 especially for lower extremity surgery, where a combination of nerve blocks is usually required, potentially resulting in higher plasma levels of local anaesthetic.

Ultrasound imaging techniques enable the anaesthesiologist to secure an accurate needle position, and monitor the distribution of the local anaesthetic solution in real time, with reported potential advantages of improved nerve block effectiveness, faster onset times, and smaller volumes of local anaesthetic solution required to produce a successful block.4–7

Using ultrasound guidance to locate the femoral nerve has been claimed to minimize the amount of local anaesthetic solution required to produce a successful surgical block.3,4 We therefore conducted this prospective, randomized, up-and-down, double-blinded investigation to test the hypothesis that ultrasound guidance can reduce

†Dr Casati sadly died in a tragic accident in April, 2007. The other authors of this article would like to acknowledge the fact that he was a great man and an internationally acclaimed regional anaesthesiologist.
the minimum effective anaesthetic volume (MEAV) required to block the femoral nerve compared with nerve stimulation guidance and an immobile needle technique.

**Methods**

With Ethical Committee approval, 60 ASA physical status I–II inpatients, aged 18–80 yr, undergoing elective knee arthroscopy under combined sciatic–femoral nerve block were studied after giving written informed consent. Patients with clinically significant coagulopathy, infection at the injection site, allergy to local anaesthetics, severe cardio-pulmonary disease, body mass index >35, diabetes mellitus or other neuropathies, and patients receiving major opioid for chronic analgesic therapy were excluded. After arrival in the operating theatre, an 18 gauge i.v. catheter was placed at the forearm contralateral to the operated limb, and standard premedication was given i.v. (midazolam 0.03 mg kg\(^{-1}\)). Standard monitoring was used throughout the procedure, including non-invasive arterial pressure, heart rate, and pulse-oximetry.

All blocks were always placed by one of the same two investigators (A.C. or G.D.), who had substantial expertise in regional anaesthesia techniques. First, we performed a sciatic nerve block with 12 ml of mepivacaine 2% using the sub-gluteus approach and a double injection technique with a nerve stimulator (Plexygon, Vygon, France). The designated volume of local anaesthetic was equally divided between plantar flexion (tibial nerve) and dorsiflexion (common peroneal nerve) of the foot.

Afterwards, the patient was turned to the supine position to place the femoral nerve block. Femoral nerve block was performed with a 0.5% solution of ropivacaine (Naropin, Astra, Sweden). Using a computer-generated sequence of random numbers, and a sealed envelope technique, patients were randomly allocated to receive a femoral nerve block using either nerve stimulation (group NS, \(n=30\)) or ultrasound (group US, \(n=30\)) guidance.

In the NS group, the nerve location was performed with the aid of a nerve stimulator using a 22 gauge, 5 cm long, short-bevelled, Teflon-coated stimulating needle (Locoplex, Vygon, Ecouen, France). The nerve stimulator was set with a pulse duration of 0.05 ms, a current intensity of 1 mA, and a frequency of 2 Hz, with the block needle always attached to the negative pole of the nerve stimulator. The stimulating needle was inserted lateral to the femoral artery at the level of the inguinal crease and oriented cranially with a 45° angle with the patient’s skin. The stimulating needle was then advanced until elicitation of the contraction of the quadriceps muscle with movement of the patella. Then, the stimulating intensity was progressively reduced to \(\leq 0.4\) mA, maintaining the proper muscular twitch. After the injection of 1 ml of local anaesthetic stopped the twitch, the designated volume of local anaesthetic was injected with 5 ml incremental boluses and repeated aspirations.

In the US group, nerve location was performed using a 5 cm, 10 MHz linear probe (LOGIQ Book XP, GE Healthcare, Milan, Italy). After examination of the anatomy of the femoral artery and vein, the femoral nerve was located 1 cm laterally to the femoral artery and under the iliopectinal fascia. Then, a 22 gauge, 5 cm long, short-bevelled, Teflon-coated needle (Locoplex, Vygon, Ecouen, France) was inserted at the level of the inguinal crease 1 cm distal to the probe with a 30° cephalad angle to the patient’s skin and advanced toward the femoral nerve.\(^8\)–\(^7\) Direct visualization of the needle tip was maintained with ultrasound while inserting the needle, until optimal positioning of the needle tip was achieved within the fascial space as close as possible to the femoral nerve. Then, the designated volume of local anaesthetic was injected slowly with 1 ml incremental aliquots with direct sonographic visualization of the spread of the local anaesthetic within the fascial space around the femoral nerve. Nerve stimulation was not used.

After completion of nerve block placement, sensory and motor blocks were evaluated every 2 min for the first 10 min after injection, and then every 5 min until 30 min after injection by an independent observer, who was not present during block placement, and was double-blinded to both the location technique used and the injected volume. Sensory block of the femoral nerve was assessed by evaluating the presence or loss of a sharp sensation with pinprick testing (20 gauge hypodermic needle) delivered in the central sensory region (area propria) of the vastus medialis, vastus intermedius, and vastus lateralis nerves.\(^8\)–\(^10\) To evaluate the motor block of the femoral nerve, we considered only the strength of quadriceps muscle. As hip flexion is partly supplied by the psoas muscle, which is not blocked with femoral nerve block, we evaluated the ability or inability to extend the leg of the operated limb against gravity, after the hip was passively flexed at 45° by the double-blinded observer.\(^9\)\(^10\) We arbitrarily defined a 30 min period as a clinically relevant time to produce effective nerve block. Effective femoral nerve block was defined as complete loss of a sharp sensation at pinprick testing in the central sensory area of the vastus medialis, vastus intermedius, and vastus lateralis nerves with complete inability to elevate the foot of the operated limb from the operating table after the double-blinded observer passively flexed the hip at 45°.

According to previous investigations,\(^9\)\(^10\) the initial volume of local anaesthetic solution was 12 ml, while the outcome of each patient’s response determined the dose for the subsequent patient. When effective femoral nerve block, as defined above, was achieved within 30 min after injection, the volume of local anaesthetic solution for the next patient was decreased by 3 ml (15 mg). Conversely, when effective femoral nerve block was not observed, the volume of local anaesthetic solution for the next patient was increased by 3 ml (15 mg). In those patients with ineffective block of the femoral nerve, supplemental
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anaesthesia with intraarticular lidocaine (20 ml lidocaine 2% with 1/200 000 adrenaline) and i.v. fentanyl (0.1–0.2 mg) were given before starting surgery. If this was not adequate to complete surgery, propofol infusion with placement of a laryngeal mask airway were given.

The day after surgery, complete recovery of neurologic function on the operated limb was checked, and the occurrence of untoward events, including paraesthesia, dysesthesia, or motor deficits, were recorded.

Statistical analysis

The main outcome variable was the MEAV of ropivacaine 0.5% providing adequate sensory and motor blocks of the femoral nerve in 50% of patients (MEAV50). To calculate the MEAV50 of ropivacaine 0.5% with the sequential up-and-down allocation technique in each group, we predetermined a minimum a priori number of independent negative–positive up-and-down deflections of ≥5.11,12 Power calculations were based on the mean and standard deviations of MEAV50 of ropivacaine 0.5% required to block the femoral nerve determined in previous investigations.9,10 We considered a 3 ml difference in the main outcome variable with an effect size to standard deviation ratio of 0.75 as clinically relevant. A minimum of 28 patients per group were required to detect the designated difference in the MEAV50 of ropivacaine 0.5% providing adequate surgical block of the femoral nerve within 30 min after the injection, accepting a two-tailed α-error of 5%, and a β-error of 10%.13 Statistical analysis was performed using the program Systat 7.0 (SPSS, Inc., Chicago, IL, USA). The MEAV50 (95% CI) of ropivacaine 0.5% providing adequate block of the femoral nerve was calculated from the midpoints of pairs of the concentrations from consecutive patients in which a negative response (inadequate nerve block within 30 min after injection) was followed by a positive one (adequate nerve block within 30 min after injection).11,12 The data were further analysed with a probit transformation and a logistic regression analysis to calculate the volume of ropivacaine 0.5% required to produce femoral nerve block within 30 min after injection in 50% (ED50) and 95% (ED95) of subjects. Comparisons of continuous variables between the two groups were performed using the Mann–Whitney U-test. Categorical variables were analysed using a contingency table analysis with Fisher’s exact test. Continuous variables are presented as mean (sd), 95% CI, or both or median (range). Categorical variables are presented as number (per cent). A value of \( P \leq 0.05 \) was considered significant.

Results

No differences in anthropometric variables were observed between the two groups (Table 1).

Figure 1 shows the sequences of positive and negative responses recorded in consecutive patients of the two groups. The mean (sd) volume of ropivacaine 0.5% resulting in complete block of the femoral nerve in 50% of cases (MEAV50) according to the up-and-down staircase method 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 ED50 and ED95 calculated with the probit transformation and logistic regression analysis were 11 ml (95% CI, 8–19 ml) and 22 ml (95% CI, 13–36 ml) in group US, and 22 ml (95% CI, 14–30 ml) and 41 ml (95% CI, 24–66 ml) in group NS, respectively.

Fifteen patients in group US (50%) and 17 patients in group NS (56%) showed a negative response 30 min after block placement, with an incomplete block of the femoral nerve at the end of the study. After recording the presence of a negative response according to the up-and-down sequence, these patients received intra-articular infiltration and i.v. fentanyl supplementation to allow surgery. This strategy was adequate to complete surgery uneventfully in all patients except three [one in group US (3%) and two in group NS (6%)], who required propofol infusion (5 mg kg\(^{-1}\) h\(^{-1}\)) and placement of a laryngeal mask airway to complete surgery.

No severe side-effects were reported in either group, and postoperative pain control was adequately covered in both groups with administration of oral non-steroidal anti-inflamatory drugs at fixed intervals and with rescue tramadol _per os_ if needed. No neurological complications were reported at the 24 h follow-up, and complete recovery of sensory and motor functions was observed in all studied patients.

Discussion

The ability to identify correctly nerves involved in surgery, and put an adequate dose of local anaesthetic around them, is a crucial factor in determining the success rate of peripheral nerve blocks.1,12 The traditional methods used for nerve location (elicitation of paraesthesia or motor response) have a low sensitivity for detection of needle-to-nerve contact.14 Ultrasound guidance has been introduced into clinical practice as a possible alternative to identify peripheral nerves, offering the potential advantage of optimizing the spread of the local anaesthetic solution around the nerves under sonographic vision.4–7 15 16

Table 1 Anthropometric variables of studied patients [results are presented as median (range) or count]

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<thead>
<tr>
<th></th>
<th>Group US (n=30)</th>
<th>Group NS (n=30)</th>
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<tbody>
<tr>
<td>Age (yr)</td>
<td>52 (18–80)</td>
<td>52 (24–75)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>74 (52–92)</td>
<td>70 (45–113)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>172 (160–190)</td>
<td>170 (145–196)</td>
</tr>
<tr>
<td>Gender (male/female)</td>
<td>12/18</td>
<td>16/14</td>
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<td>ASA physical status</td>
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results of this prospective, randomized, double-blinded study showed that ultrasound guidance allows reduction of the MEAV solution required to produce an effective surgical block of the femoral nerve within 30 min after injection compared with nerve stimulation guidance.

Several studies reported better quality of nerve block and shorter onset times when using ultrasound rather than nerve stimulation guidance for upper and lower extremity blocks, and suggested the possibility of reducing the volume of local anaesthetic solution required to achieve an adequate surgical block compared with previous techniques of nerve location. In agreement with the present findings, Marhofer and colleagues reported a higher success rate and a shorter onset time of three-in-one block obtained with 20 ml of bupivacaine 0.5% injected with ultrasound guidance compared with the injection of 30 ml of the same solution using nerve stimulation guidance.

Minimizing the amount of local anaesthetic solution required to achieve an adequate surgical block may increase the safety of peripheral blocks by reducing the risk for overdosing, which has been reported as the main risk factor for severe complication during peripheral nerve blocks, and suggested the possibility of reducing the volume of local anaesthetic solution required to achieve an adequate surgical block compared with previous techniques of nerve location. In agreement with the present findings, Marhofer and colleagues reported a higher success rate and a shorter onset time of three-in-one block obtained with 20 ml of bupivacaine 0.5% injected with ultrasound guidance compared with the injection of 30 ml of the same solution using nerve stimulation guidance.

The clinical relevance of a MEAV value might be questioned, because it is only one point on a dose–response curve. Nonetheless, the ‘ED’ concept is widely used in pharmacology and clinical research when comparing relative potencies of different treatments, and it has been applied to determine dose–effect relationships in different fields of anaesthesia research, including peripheral nerve blocks. Moreover, we also calculated the ED95, which may be more relevant to daily practice, confirming the clinically relevant reduction of the volume required to produce a similarly effective surgical block.

The main drawback of the method used in the present study is that about 50% of the studied patients had an incomplete nerve block. Such a pitfall occurs with up-and-down methodology, and a catheter is usually left in place to overcome ethical issues of such a method. In the present investigation, we did not position a femoral catheter for analgesic implementation, because pain control during knee arthroscopy can be easily provided by intra-articular infiltration and i.v. opioids, which actually

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**Fig 1** The up-and-down sequence of volumes of ropivacaine 0.5% required to produce effective sensory and motor block of the femoral nerve using either ultrasound (group US, n=30) or nerve stimulation guidance (group NS, n=30).
allowed surgery to be completed in all patients with a negative response except for three patients, who also required general anaesthesia for completion of surgery.

It must be pointed out that ultrasound imaging technology remains the most subjective and operator-dependent imaging technique; Furthermore, using sonography for nerve location requires that the physicians learn new skills and approaches to nerve blocks, with a new learning curve also for trained physicians. Evaluating the learning curve associated with sonography or ultrasound guidance by inexperienced anaesthesia residents, Sites and colleagues 21 reported that physicians with little or no ultrasound experience can rapidly learn and improve their speed and accuracy in performing a simulated ultrasound procedure. In the present study, anaesthesiologists with substantial expertise in regional anaesthesia techniques and ultrasound guidance for nerve location placed all blocks. However, the operator-dependent variability in confidence with ultrasound guidance and nerve blocks may reduce the external validity of the present findings with different operators and clinical settings.

In conclusion, most of the theoretical claimed advantages of sonographic visualization over electrical stimulation for nerve location still need to be evaluated in properly designated, randomized, controlled trials. The results of this investigation support initial reports, 4–7 showing that ultrasound guidance for femoral nerve block provided a 42% reduction of the MEAV required to produce a surgical block compared with nerve stimulation guidance.

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