Minimum volume of local anaesthetic required to surround each of the constituent nerves of the axillary brachial plexus, using ultrasound guidance: a pilot study

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Background. The minimum effective volume of local anaesthetic needed to provide effective analgesia of the four main branches of the axillary brachial plexus is unknown. This study was performed to determine the minimum volume of local anaesthetic required to surround the nerves of the axillary brachial plexus and document onset and duration of sensory and motor effects.

Methods. We enrolled 19 ASA I–II patients undergoing hand or forearm surgery. The four nerves of the axillary plexus were identified with ultrasound guidance. Lidocaine 1.5% with epinephrine 1:200 000 was loaded into a syringe driver. A 22 G needle was inserted in the long axis to each nerve and injection commenced using the bolus function (600 ml h⁻¹). The needle was repositioned until the nerve was completely surrounded. The bolus dose in millilitres displayed on the syringe driver was recorded. This was repeated for each nerve. The degree of sensory and motor block was recorded as secondary outcomes.

Results. The mean (95% CI) volume to surround each nerve was: radial 3.42 (2.84–3.99) ml, median 2.75 (2.31–3.19) ml, ulnar 2.58 (2.14–3.03) ml, and musculocutaneous 2.30 (1.96–2.64) ml. The mean (95% CI) onset time for complete sensory block was: radial 22.5 (13.5–31.5) min, median 26.6 (17.8–35.4) min, ulnar 26.6 (17.8–35.4) min, and musculocutaneous 15.8 (7.45–24.2) min. The mean (95% CI) last recorded time with complete block was: radial 137.1 (105.6–168.7) min, median 144.7 (123.4–166.0) min, ulnar 183.2 (158.1–208.2) min, and musculocutaneous 158.3 (131.8–184.9) min. Seven patients required additional local anaesthetic infiltration and two required i.v. analgesia. No patient required conversion to general anaesthesia for surgery.

Conclusions. We found that it is possible to surround each nerve of the axillary brachial plexus with 2–4 ml of local anaesthetic. We speculate that increasing this volume would produce blocks of quicker onset and longer duration while still using smaller volumes than previously thought.

Br J Anaesth 2010; 104: 633–6

Keywords: anaesthetic techniques, regional, brachial plexus; anaesthetics local, lidocaine; drug delivery, volume; ultrasound

Recent years have seen a substantial increase in the use of ultrasound as an aid to performing regional anaesthesia. Proponents of the technique can point to significant advances in terms of speed of block performance, greater block success, and faster onset times. It would be expected that direct visualization of target structures with ultrasound should lead to more accurate delivery of injectate. This has been shown to be true, and ultrasound guidance has led to comparable anaesthesia with reduced volumes of injectate, compared with other means of nerve location.

Traditional high-volume regional blocks such as the axillary brachial plexus or femoral 3-in-1 block have relied on volumes of injectate of up to 40 ml to achieve surgical anaesthesia. Much of this volume, however, may diffuse into surrounding soft tissues or undergo vascular...
uptake and therefore not contribute to anaesthesia. It seems reasonable to suggest that the key to a successful block is to surround as much of the nerve bundle as possible with local anaesthetic. With ultrasound guidance, this potentially can be done with very small volumes of local anaesthetic. At present, the minimum volume required to surround each of the four main branches of the axillary brachial plexus is unknown. Furthermore, having surrounded the nerve with local anaesthetic, the minimum volume required for effective anaesthesia is also unknown.

The primary outcome measure of this study was to establish the minimum volume of local anaesthetic required to surround each of the constituent nerves in the axillary brachial plexus and determine whether this would produce a quality of anaesthesia suitable for surgery. The secondary outcome measures were times to onset and offset and extent and duration of sensory and motor block.

Methods

After local research ethics committee approval and written informed consent, 19 ASA grade I or II patients undergoing arm or forearm surgery at the Ulster Hospital, Dundonald, were enrolled into the study. Exclusion criteria included patient refusal, age <16 yr, coagulopathy, allergy to local anaesthetics, and a BMI >35 kg m⁻². All patients were undergoing minor orthopaedic or plastic surgical operations. All blocks were performed by the same operator (G.K.H.). Patients received sedation with midazolam 0.15–0.25 mg kg⁻¹ and fentanyl 50–100 µg i.v. before commencement of the regional block. Full monitoring was placed and supplemental oxygen administered throughout. The skin surface of the axilla and arm was prepared with alcoholic chlorhexidine solution. A 6–13 mHz linear ultrasound probe (Vivid i®, General Electric, USA) was used to obtain an image of the axillary artery. The four main branches of the plexus at this level were identified as follows: following the artery proximally from the elbow to the forearm, the ulnar nerve proximally from the ulnar groove at the elbow back to the axilla, and identifying the radial nerve spiralling down round the humerus and retracing it back to the axilla. The musculocutaneous nerve was identified by its characteristic flattened appearance, lying in the fascial place between the biceps and coracobrachialis muscles. Lidocaine 1.5% with 1:200 000 epinephrine was drawn up in a 60 ml syringe (Monoject TM, Kendall Healthcare, USA) and connected to a 22G regional block needle (BD, NJ, USA) via connection tubing [Protect-A-Line (832), Vygon, France]. A syringe driver (Alaris® GH, Cardinal Health, UK) was used to inject the solution using the bolus function, set at 600 ml h⁻¹. Once the four nerves had been identified, injection round each nerve was performed. The needle was positioned beside the nerve and an assistant activated the bolus function on command. The delivered dose (to one decimal place) displayed on the pump was recorded with repositioning and further bolus injection, so that the minimum volume of local anaesthetic required to surround the nerve bundle with a ‘halo’ was used. The total dose recorded for each nerve was then documented. Where possible the radial, median, and ulnar nerves were blocked from the one skin puncture site, the musculocutaneous nerve usually being blocked from a second puncture.

Data collection

On completion of injection round each nerve, data regarding sensory and motor block were collected. Sensory block was evaluated for each nerve distribution using iced water to test cold sensation, comparing the anaesthetized arm with the contralateral arm, and graded on a three-point scale (1, no difference between sides; 2, some difference between arms but cold still sensed in the blocked arm; 3, no cold sensation in the blocked arm). Motor block for each nerve was evaluated by asking the patient to flex the arm (musculocutaneous nerve), extend the flexed arm and wrist (radial nerve), flex the wrist and oppose the second and third fingers and thumb (median nerve), flex and oppose the fourth and fifth fingers towards the thumb (ulnar nerve) and was graded as 1, no change; 2, reduced contraction; 3, no contraction. Data were collected every 5 min for the first 30 min, at 45 and 60 min, and every 30 min thereafter up to 6 h.

Results

Nineteen consecutive adult patients having hand or forearm surgery were recruited. The mean volume of local anaesthetic required to surround each of the individual nerves and times to onset and offset of effective sensory block are shown in Tables 1–3.

Examination of the Q–Q plots indicated a normal distribution for all of these figures with the exception of duration of sensory block for the musculocutaneous nerve.

Table 1 Mean (95% CI) volume required to surround nerve (ml)

<table>
<thead>
<tr>
<th>Nerve</th>
<th>Mean</th>
<th>95% CI</th>
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</thead>
<tbody>
<tr>
<td>Radial</td>
<td>3.42</td>
<td>2.84–3.99</td>
</tr>
<tr>
<td>Median</td>
<td>2.75</td>
<td>2.31–3.19</td>
</tr>
<tr>
<td>Ulnar</td>
<td>2.58</td>
<td>2.14–3.03</td>
</tr>
<tr>
<td>Musculocutaneous</td>
<td>2.30</td>
<td>1.96–2.64</td>
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Table 2 Mean (95% CI) time to effective sensory block (min)

<table>
<thead>
<tr>
<th>Nerve</th>
<th>Mean</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial</td>
<td>22.5</td>
<td>13.5–31.5</td>
</tr>
<tr>
<td>Median</td>
<td>26.8</td>
<td>18.5–35.0</td>
</tr>
<tr>
<td>Ulnar</td>
<td>26.6</td>
<td>17.8–35.4</td>
</tr>
<tr>
<td>Musculocutaneous</td>
<td>15.8</td>
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with a small number of outliers, that is, there was a positive skew.

Seven out of 19 patients required additional local anaesthetic infiltration by the surgeon and two patients required an i.v. bolus of analgesic (up to 100 µg fentanyl). No patient required conversion to general anaesthesia for surgery.

**Discussion**

In this study, we found that with accurate ultrasound guidance, the individual nerves of the axillary brachial plexus can be surrounded with very low volumes of local anaesthetic, especially when compared with the traditionally larger volumes used with nerve stimulation or transarterial techniques. We also found that when using these very low volumes, the onset of anaesthesia was relatively slow and duration short.

The main advantage of ultrasound in regional anaesthesia is that it allows visualization of nerves, surrounding structures, and needle placement, and crucially, the real-time interaction between nerves and injectate. The increased accuracy of deposition and knowledge of spread around the nerve has led to greater consistency of block success when ultrasound guidance is used. Accurate deposition of drug on the nerve, with real-time visualization, has also been shown to reduce the time for onset of the block. Anecdotal experience in the field of regional anaesthesia suggests that surrounding the target nerve with local anaesthetic is the key to a successful block. The primary outcome measure of our study was to document the minimum volume required to do this, and we confirmed that low volumes could be used.

Our data support other recent works using lower volumes of anaesthetic in nerve and plexus blocks. O’Donnell and Iohom were able to surround axillary plexus nerves, and gain adequate anaesthesia, with as little as 1 ml of lidocaine 2%. This volume of injectate requires a degree of operator skill for accurate placement of the injection. It also raises the question of whether drug concentration rather than dose is most important in establishing an effective block, though it is beyond the scope of our study to contribute to this particular debate. Other recent studies have also used minimal or lower volumes for nerve or plexus anaesthesia in the upper limb. Eichenberger and colleagues injected small volumes of mepivacaine 1% in and around the ulnar nerve in the forearm, to identify the minimum volume required to provide anaesthesia. In contrast, Duggan and colleagues found that using ultrasound did not significantly reduce the required volume of anaesthetic for supraclavicular blocks.

We found some difficulties accurately identifying the radial nerve when performing the blocks in our study. To aid identification, the course of the nerve was retraced from distal to proximal round the shaft of the humerus back to the axilla. Nevertheless, it was often necessary to inject more drugs round the radial nerve to ensure that it was surrounded. Several of the patients who required block supplementation had insufficient radial nerve block and more accuracy for this nerve may have resulted in greater overall block success. The higher volume required to surround the radial nerve probably reflects the relative difficulty of identifying this nerve in the axilla and ensuring that it was surrounded with anaesthetic. It may have been helpful to use nerve stimulation when performing the blocks for this reason, as suggested for the radial nerve by Wong and colleagues recently. In contrast, the musculocutaneous nerve tended to be surrounded with a relatively low volume, probably explained by its location between the two fascial planes of biceps and coracobrachialis. We also noted that in most cases, there was a relatively selective sensory block with motor fibre sparing, the exception being the musculocutaneous nerve where a complete motor block was usually achieved within 15 min of injection. We speculate that this more rapid and complete effect could be due to the location of the musculocutaneous nerve between the facial planes of the biceps and coracobrachialis muscles.

In the majority of cases, we found that anaesthesia was sufficient for surgery. Seven out of 19 patients required some form of block augmentation by the surgeon and two further patients required i.v. fentanyl to facilitate surgery. In all of these cases, however, there was some residual block after operation and we considered that perceived block failure was possibly due to the slow onset rather than an absence of anaesthesia. Nevertheless, our findings suggest that injecting such small volumes may not be completely reliable in the clinical setting.

Our study supports the idea that low volumes of anaesthetic can achieve the required sensory anaesthesia for surgery, while minimizing the duration of the block. This could have implications for day surgery, allowing more scope for regional anaesthesia, when it may be reassuring for the block to have worn off before hospital discharge. However, the slower onset of motor block may be a limiting factor and larger volumes may be required to remedy this. Future studies are planned to investigate the ideal volume of anaesthetic to inject for individual nerves and plexus blocks using ultrasound-guided injections.

In conclusion, we found that with the aid of ultrasound, the nerves of the axillary brachial plexus can be reliably surrounded with very low volumes of local anaesthetic. These volumes can give anaesthesia sufficient in most

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### Table 3 Mean (95% CI) duration of effective sensory block (min)

<table>
<thead>
<tr>
<th>Nerve</th>
<th>Mean</th>
<th>95% CI</th>
</tr>
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<tbody>
<tr>
<td>Radial</td>
<td>137.1</td>
<td>105.6–168.7</td>
</tr>
<tr>
<td>Median</td>
<td>144.7</td>
<td>123.4–166.0</td>
</tr>
<tr>
<td>Ulnar</td>
<td>183.2</td>
<td>158.1–208.2</td>
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<tr>
<td>Musculocutaneous</td>
<td>158.3</td>
<td>131.8–184.9</td>
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cases for surgery, but further study is required to determine the optimum volume to use.

Conflict of interest
None declared.

References