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Critical Review:

Evolution and Impact of Ultrasound Guidance on Brachial Plexus Anaesthesia

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A thesis submitted in fulfillment of the requirements for the degree of Doctor of Philosophy by Research Publications

The University of Edinburgh, 2014
Abstract: Evolution and Impact of Ultrasound Guidance on Brachial Plexus Anaesthesia

Brachial plexus block (BPB) techniques provide significant benefits including better pain control, faster discharge and reduced adverse effects compared to general anaesthesia. Prior to 2005 BPBs were performed using landmark, paraesthesia or electrical nerve stimulation (PNS) methods and were associated with reasonable success (70-80%) but were still associated with risk of failure and complications.

Use of ultrasound (US) to guide local anaesthetic injection was first reported in 1989 but until 2004 remained unexplored. From 2004 we aimed to explore the feasibility, success and safety of ultrasound-guided brachial plexus blocks (USBPB) compared to techniques guided by anatomical landmarks or peripheral nerve stimulation. We hypothesized that USBPB would be feasible, have greater success and safety compared to standard methods.

In 2004 we identified the possibility of using US to place infraclavicular block (ICB) and identified a pattern of local anaesthetic spread that predicted successful block. A subsequent randomized trial found improved success of US compared to existing methods. We examined success of US-guided axillary brachial plexus block (ABPB) and found that that performance time and success were improved. In a large retrospective review of ABPB techniques we identified that US techniques were faster to perform, had a higher success and were safer compared to standard methods. We also assessed existing nerve localization methods in an observational study and found that both have poor sensitivity and specificity possibly explaining some of the limitations of these techniques. A bench study examining local anaesthetic injection using ultrasound found that both novices and experts could accurately determine local anaesthetic spread. In practice this is a useful marker for safe injection and could explain findings of increased safety with ultrasound methods.

We systematically reviewed the literature for studies examining USBPB and this demonstrated that US improves block success and performance time. Subsequent pilot work indicated that US, in addition to improving quality, could also reduce volume of local anaesthetic required for successful block and we hypothesized that for certain techniques such as interscalene block this may improve safety. We compared US-guided interscalene block (ISB) using traditional volumes (20ml) and compared with a low volume (5ml) of ropivacaine 0.5%. Results demonstrated no difference in efficacy or duration but significant reduction in respiratory (and other) complications with lower volumes. We then compared US-guided ISB to PNS using an Up and Down Sequential Allocation design to estimate the minimum effective anaesthetic volume (MEAV50) for ropivacaine 0.5% for major shoulder surgery. Our findings indicated that volumes of local anaesthetic could be dramatically reduced with US (0.9 vs 5.4ml) whilst still providing effective pain relief.

In the last ten years the cases and studies described have demonstrated that US improves BPB success and safety. For ISB US reduces volumes of local anaesthetic required for success whilst also reducing respiratory and other complications.

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Preface:

Declaration

Acknowledgements

Publications submitted in support of this thesis
Declaration:

All publications associated with this thesis were performed at the University of Toronto and published between 2004 and 2012. All work on this thesis and associated publications was either performed solely by the candidate or in collaboration with a team of colleagues at both Toronto Western Hospital and Sunnybrook Health Sciences Centre, Toronto, ON, Canada. The substantial individual contributions that the candidate made to the work are detailed in Appendix 2. This thesis has not been submitted in whole or in part for any other degree or professional qualification.

Signed:

Colin John Lindsay McCartney
26th August 2014
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Publications submitted in support of the PhD by research publications:
(see Appendix 1 and 2)(Citations: Google Scholar 2nd June 2014)


11: McCartney CJ, Patel S. Local anesthetic volume for peripheral nerve blocks: how low can (or should) we go? Reg Anesth Pain Med 2012; 37: 239-41. (1 citation)


Total citations: 954
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Figure 2: Cutaneous innervation and dermatomal supply of the upper limb (reproduced with permission from Principles and Practice of Regional Anaesthesia, 4th Ed, Oxford University Press).

Figure 3: Stepwise approach to investigation of ultrasound-guided brachial plexus block

Figure 4: Ultrasound-guided infraclavicular block. Short arrow indicates needle. PMJ=pectoralis major, PM=pectoralis minor, LC=lateral cord, PC=posterior cord, A=axillary artery, V=axillary vein, P=pleura.
List of abbreviations:

CRM: Continual reassessment method
D/M: Dixon and Massey
DSU: day surgery unit
FEV: forced expiratory volume
FVC: forced vital capacity
GA: general anaesthesia
mA: milliamperes
MEAV: minimum effective anaesthetic volume
PACU: post-anesthesia care unit
PCIA: patient-controlled interscalene analgesia
PEFR: peak expiratory flow rate
PNS: peripheral nerve stimulation
RCT: randomised controlled trial
US: ultrasound
Chapter 1: Anatomy of the brachial plexus and history of brachial plexus anaesthesia with an overview of localization techniques

Anatomy of the brachial plexus:
The nerve supply to the upper limb arises predominantly from the brachial plexus and is formed by the ventral rami of C5-8 and T1 with a variable supply from C4 and T2 (see figure 1). After emerging from the intervertebral foraminae the roots combine to form three trunks; superior, middle and inferior that then pass between the anterior and middle scalene muscles and emerge posterior and lateral to the subclavian artery at the level of the first rib. Each trunk divides into an anterior and posterior division as it passes over the first rib and under the clavicle.

Figure 1: Anatomy of the brachial plexus (reproduced with permission from Principles and Practice of Regional Anaesthesia, 4th Ed, Oxford University Press).

<table>
<thead>
<tr>
<th>TERMINAL BRANCHES</th>
<th>CORDS</th>
<th>DIVISIONS</th>
<th>TRUNKS</th>
<th>ROOTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axilla</td>
<td>First rib</td>
<td>Scalene muscles</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The three posterior divisions combine to form the posterior cord, the anterior divisions of the upper and middle trunk form the lateral cord and the anterior division from the inferior trunk forms the medial cord. The cords are formed as they pass distal to the first rib and into the apex
of the axilla. At this level the cords lie, as described by their name (lateral, posterior and medial), around the 2\textsuperscript{nd} part of the axillary artery before passing the lower border of pectoralis major and forming the terminal branches of the brachial plexus. The four main terminal nerves are the radial (from the posterior cord), ulnar (from the medial cord), median (medial and lateral cords) and musculocutaneous nerves (lateral cord). A number of other nerves arise from the brachial plexus during the brachial plexus course in the neck and axilla (figure 1) but are not further described here. The dermatomal supply of the upper limb is shown in figure 2. Full description is not made here however each approach to the brachial plexus is characterised by particular spread to certain dermatomal areas of the upper limb.

Figure 2: Cutaneous innervation and dermatomal supply of the upper limb (reproduced with permission from Principles and Practice of Regional Anaesthesia, 4\textsuperscript{th} Ed, Oxford University Press).
Common anatomical variations of the brachial plexus:

Several anatomical variations of the brachial plexus occur and the regional anaesthetist needs to be aware of these to optimize performance of brachial plexus block. At the interscalene level the C5 and C6 brachial plexus roots can lie within the body of the anterior scalene muscle(1) and in approximately 5% of cases the C5 root descends anterior to the anterior scalene muscle(2). At the supraclavicular level the superior trunk can lie anterior or pierce the sheath of the anterior scalene muscle instead of lying between the two scalene muscles(3). Recent ultrasound studies also confirm this variation(4) and also variations in the configuration of the trunks at the supraclavicular level. In 66% the brachial plexus changes from a vertical orientation at the interscalene level to horizontal at the supraclavicular level and in the remaining 33% the trunks lie clumped together at the supraclavicular level(4). At the infraclavicular level instead of the cords of the plexus lying around the second part of the axillary artery it is possible for all three cords to lie lateral and superior to the artery(5). Finally, in the axilla, variations of the position of the musculocutaneous, median and ulnar nerves can occur. The musculocutaneous nerve branches off from the lateral cord at a variable level from the apex of the axilla to the midhumeral level. The median nerve can vary from a lateral to a medial position on the axillary artery while the ulnar nerve can either lie between the axillary artery and vein or medial to the axillary vein. The venous anatomy in the axilla is highly variable with anything from a single vein to several veins being present(6).

Approaches to the brachial plexus:

In the last century various approaches to the brachial plexus have been developed mainly to improve simplicity, safety and success of the technique(7). The first brachial plexus blocks were reported in 1884 by William Halstead and Richard Hall of New York(8). Predominantly experimenting on medical students and each other they used cocaine to anaesthetise many peripheral nerves in the body including nerves of the brachial plexus. Kulenkampff developed the first percutaneous brachial plexus technique in 1911 by placing local anaesthetic around the supraclavicular brachial plexus(9). Later that year Hirschel (10) also developed an axillary technique. In 1928 Kulenkampff and Persky(11) demonstrated the safety of their supraclavicular technique by publishing an experience of over 1000 blocks and the first continuous method was developed by Ansbro in 1946(12). In 1961 De Jong(13) added to the
work of Burnham(14) in developing an axillary perivascular technique and demonstrated that sufficient volume (minimum of 42ml in the average adult) was necessary to anaesthetize the musculocutaneous and axillary nerves. Further utilizing the concept of a fascial sheath Winnie and Collins developed the subclavian perivascular technique at the supraclavicular level in 1964(15) and in 1970 Winnie described the interscalene technique(7) but noting the limited spread to the inferior trunk. Raj et al described the infraclavicular method in 1973 in an attempt to reduce the risk of pneumothorax and also reduce limitations of arm positioning necessary with the axillary method(16). Each technique has its advantages and limitations (see table).
Table 1: Indications, advantages, limitations and complications of each approach to the brachial plexus

<table>
<thead>
<tr>
<th></th>
<th>Surgical indications</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interscalene</td>
<td>Shoulder, humerus and elbow</td>
<td>Profound shoulder analgesia</td>
<td>Limited coverage of C8/T1.</td>
<td>Neuraxial and vertebral artery injection. Phrenic block and Horner’s syndrome</td>
</tr>
<tr>
<td>Supraclavicular</td>
<td>All procedures distal to the shoulder</td>
<td>Rapid onset and extensive coverage</td>
<td>Risk of pneumothorax</td>
<td>50% risk phrenic block</td>
</tr>
<tr>
<td>Infraclavicular</td>
<td>As supraclavicular</td>
<td>Extensive coverage. Useful for catheter fixation. Reduced risk pneumothorax</td>
<td>Deep target. Risk of haematoma if vessel punctured</td>
<td></td>
</tr>
<tr>
<td>Axillary</td>
<td>Forearm and hand surgery</td>
<td>No risk of pneumothorax or phrenic block</td>
<td>Not possible if unable to abduct arm. Risk of failure to block lateral forearm</td>
<td>Highest risk of intravascular injection</td>
</tr>
</tbody>
</table>

The interscalene block at the level of the brachial plexus roots and proximal trunks predominantly affects the superior and middle trunks of the plexus so that the shoulder, lateral arm, forearm and hand is anaesthetized with standard volumes (30-40ml) of local anaesthetic. However this proximal and superior approach at the C6-C7 level tends not to spread to the inferior trunk (C8-T1)(17) so that anaesthesia of the medial arm, forearm and hand is less
reliable (see figure 2). The interscalene block is therefore a commonly used technique for shoulder and proximal arm surgery but not distal or medial arm surgery.

The supraclavicular and infraclavicular approaches anaesthetise the distal trunks and cords of the brachial plexus respectively and provide reliable anaesthesia of the whole upper limb for supraclavicular block(17) but without shoulder anaesthesia for the infraclavicular technique.

Finally the axillary technique provides reliable anaesthesia predominantly of the forearm and hand and careful identification of the musculocutaneous nerve needs to be performed to ensure anaesthesia of the lateral forearm and anatomical ‘snuffbox’ if needed(17).

**Side effects and complications:**

Each technique is associated with recognised side effects and complications that may determine specific contraindications to use of the block. The interscalene technique is associated with 100% block of the phrenic nerve with standard volumes of local anaesthetic(18) and this causes a 15-25% reduction in vital capacity that may cause respiratory distress in individuals with reduced respiratory reserve. In addition block of the recurrent laryngeal nerve (causing hoarseness) and sympathetic chain (causing Horner’s syndrome) is common(19). Less common complications including epidural spread are possible and needle trauma to many structures within the posterior and anterior triangle of the neck have been reported.

The supraclavicular block prior to the use of ultrasound was associated with a 0.5-3% incidence of pneumothorax(20) and a 50% incidence of phrenic nerve block. It is unclear at the present time if ultrasound has reduced the incidence of phrenic nerve block or pneumothorax(17).

Infraclavicular block has a much reduced incidence of pneumothorax compared to the supraclavicular technique and also phrenic nerve block is very uncommon(17) and the axillary technique has similar qualities except that pneumothorax has not been reported because of the injection site distant from the pleura. All of the brachial plexus techniques, especially those using larger volumes of local anaesthetic, expose the patient to risk of intravascular injection with systemic cardiovascular and central nervous system complications such as seizure and cardiac arrhythmia or collapse. Practitioners tend to restrict local anaesthetic doses to known toxic dose ranges(21) but these toxic doses are based on theoretical absorption from tissue spaces and do not reflect the effect of direct intravascular injection of very small volumes of concentrated local anaesthetic which can cause cerebrovascular (seizure) or cardiovascular (cardiac arrhythmia or arrest) events well below the described toxic dose.
Nerve injury is possible with any of the approaches to the brachial plexus and is associated with patient, anaesthetic and surgical factors(22). Patients with a history of neurological impairment or diabetes may be at higher risk of neurological injury because nerves are more susceptible to the physical and chemical stresses that are applied during regional anaesthesia and surgery. Nerves can also be damaged by direct trauma (either due to needle, positioning or tourniquet). Peripheral nerves are surrounded by three layers of tissue: the epineurium, perineurium and endoneurium. Although current teaching suggests that it is undesirable to inject within any of these layers, recent evidence suggests that it is injection within the perineurium that is most likely to cause significant injury(23). Nerve injury can also be caused by patient positioning or tourniquet pressure during surgery. Temporary motor or sensory symptoms are common after upper limb surgery (up to 3%) however brachial plexus block techniques can produce permanent nerve injury and large cohort studies suggest an incidence of 1:5000-1:10,000(24).

Localizing techniques for brachial plexus block:

All methods of localising the brachial plexus prior to 1980 used either landmarks or patient-reported sensations of paraesthesia to indicate proximity of the needle tip to the nerves being sought. Although these techniques produced satisfactory results in expert hands they were difficult to teach and associated in some cases with unacceptable risk of complications. For example, the Kolenkampff Supraclavicular technique was associated with a 3% incidence of pneumothorax. Winnie(15) developed a supraclavicular method (subclavian perivascular technique) that reduced the risk of pneumothorax(25) to less than 1% and an interscalene method(7) that was designed to reduce the risk of placing the needle tip inadvertently within the neuraxis (which lies a few millimetres medially at the interscalene level). In addition use of the paraesthesia method relies on subjective complaints of paraesthesiae from the patient that are sometimes difficult to elicit and produce both false positive and negative reports from the patient (see chapter 6).

Although peripheral nerve stimulation (PNS) had been used as early as 1912 it was only in the 1980’s that the method began to increase in popularity to identify nerves of the brachial plexus(26). This method uses a low current (0.5-1.5mA) provided through an insulated needle to produce motor stimulation of mixed peripheral nerves. For the first time practitioners were able to obtain an objective endpoint of needle to nerve proximity. Studies were performed examining the benefits of the use of peripheral nerve stimulation both compared to prior methods(27) and comparing single or multiple endpoints with PNS(28). These studies have
demonstrated equivocal benefits of PNS over existing methods and that although failure rate was as high as 40% with a single PNS endpoint(29) the use of multiple PNS endpoints significantly improved success(28). However although PNS could confirm needle tip to nerve proximity it did not guarantee spread of local anaesthetic around the nerve. This meant that a high rate of false positive and negative endpoints were possible(30, 31). The success rate with PNS techniques was often very high (between 90-98%)(32) but in some studies remained as low as 50%(33).

Until the early 2000s brachial plexus block was performed either using landmark, paraesthesia or PNS methods and with success rates ranging from 50- 95% depending on approach and technique used. The variability in success rate was most likely related to the high false negative and positive rates with the use of existing nerve localisation techniques(30, 31, 34) or due to unrecognized inadequate spread of local anaesthetic. Many practitioners tried to overcome this problem by using large volumes of local anaesthetic that increased block success(35) but this in turn could increase block related complications either due to spread to associated local structures (e.g. phrenic nerve and interscalene block) or systemic spread and cardiovascular or central nervous system effects(24). Brachial plexus blocks remained a technique for use by trained subspecialists and a significant risk of block failure still existed even in expert hands. A better method was needed both to improve nerve localization methods and also to better determine adequate spread of local anaesthetic and improve onset and efficacy.

Ultrasound (US) technology offered a portable and minimally invasive method of identifying nerves and in the early 2000s was starting to offer reasonable images of superficial peripheral nerves. In addition US equipment was becoming more portable and affordable for use outside of the domain of the radiology department. The first successful use of US to examine brachial plexus block was reported in 1989 by Ting et al in a series of 10 patients(36). In this series US was not used to guide the needle or local anaesthetic spread but was just used to confirm adequate needle tip placement. Local anaesthetic spread was examined after but not during injection. In 1994 Kapral et al(37) randomized 40 patients to either US guided supraclavicular or axillary block and were the first to directly visualize needle placement and local anaesthetic spread using US guidance although they did not examine whether the US method was superior to existing techniques. A series of radiology reports and case series determined the possibility of both visualising the brachial plexus(38, 39) and competently performing various techniques(40, 41). An unblinded randomised study by Williams et al(42) did demonstrate superiority of an US-
guided supraclavicular block compared to a PNS-guided method but only in relation to time to perform the block (5 vs 9.8 mins).

By 2004 US had been demonstrated to be a useful method for visualising brachial plexus structures and for placing local anaesthetic under direct guidance for some techniques. Many questions and controversies remained. Firstly, a debate continued about whether brachial plexus block anaesthesia provided any advantage compared to modern general anaesthetic techniques (43). Many of the brachial plexus techniques had not been described with ultrasound, whilst others, having been described had not been rigorously studied especially in comparison to existing methods. A vigorous debate about the effectiveness and advantages of US was beginning to develop (44) in the literature that was comparable to the previous debate when PNS was introduced to replace landmark and paraesthesia methods.

In 2004 brachial plexus block remained a niche technique that few anaesthetists could perform. Most practitioners of brachial plexus blocks were still using landmark and nerve stimulation methods and there had been few well designed studies either comparing brachial plexus block with general anaesthesia techniques or studies examining the potential of ultrasound in comparison to pre-existing methods of performing brachial plexus block. We therefore developed several hypotheses starting with a randomised study of brachial plexus block compared to general anaesthesia (45) and then examining the potential benefits of ultrasound-guided techniques compared to existing methods (6, 34, 46-49). Finally we examined the ability of ultrasound to reduce the volume of local anaesthetic for interscalene block and whether this could in turn reduce associated adverse effects (50, 51).
Chapter 2: Overview of methodological approach to thesis

*Rationale for investigating comparison between brachial plexus block and general anaesthesia for upper extremity surgery:*

In 2002 the use of brachial plexus block for upper extremity surgery was controversial. Purported benefits such as faster recovery, less pain and nausea compared to general anaesthesia techniques were being contested by newer generation anaesthetic agents such as desflurane, sevoflurane and propofol and the combination of multimodal analgesic techniques with drugs such as non-steroidal anti-inflammatory drugs and shorter duration lipophilic opioids(45, 52). Several prospective cohort studies had demonstrated some benefits of regional anaesthesia(53, 54) but there were no high quality randomized trials examining whether regional anaesthesia was superior to general anaesthesia.

We therefore designed our first study (45) as a high quality randomized study using an intention-to-treat methodology to compare a common method of performing brachial plexus block (transarterial axillary block) against a commonly used general anaesthesia technique for ambulatory anaesthesia. We found significant benefits to the use of brachial plexus block including better pain control in hospital, faster recovery and fewer side effects such as nausea and vomiting. The main limitation to the methods in this study was the lack of blinding however this study remains the largest randomized study comparing brachial plexus block against general anaesthesia and demonstrated the clear benefits of brachial plexus block for day case hand and forearm surgery.

A clear finding from this study was that the success rate of the axillary block technique alone was poor. Only 62% of patients had a successful block (14/50 patients required local anaesthetic or other supplementation and 5/50 patients required conversion to general anaesthesia). Other studies in the literature also demonstrated widely varying success rates for brachial plexus block(17, 55, 56). It was clear that the success rate of brachial plexus block was far from adequate and that further methods needed to be explored to improve success.
Rationale for methodological approach to ultrasound studies:

In 2004 there were few studies examining the benefits of ultrasound guidance for brachial plexus block. Our group used a stepwise method to investigate the feasibility, success and safety of ultrasound-guided brachial plexus block compared to existing methods.

Figure 3: Stepwise approach to investigation of ultrasound-guided brachial plexus block:

- **Case reports, case series and cohort studies**

- **Studies of Mechanisms**
  - Perlas et al 2006, McCartney et al 2010

- **Randomised controlled trials**

- **Systematic Review**
  - McCartney et al 2010

Prior to 2004 there were few studies of nerve imaging using ultrasound. We wanted to determine the feasibility of visualising nerve and other anatomical structures with ultrasound and whether ultrasound-guided placement of local anaesthetic could produce effective brachial plexus block. Our initial case reports and case series demonstrated the feasibility of performing ultrasound-guided nerve block techniques(49, 57). Having demonstrated feasibility we wanted to compare the new ultrasound-guided methods with the best existing methods. A study was performed to investigate the sensitivity and specificity of nerve stimulation and paraesthesia methods using ultrasound to visualize needle-nerve contact(34). We also started to perform randomized studies to compare ultrasound vs the existing standard (peripheral nerve stimulation) for various different brachial plexus block techniques(6, 46). We performed a retrospective analysis of a large case series(47) to examine differences in efficacy and adverse
effects over a larger group of patients. Finally in order to place our findings in the context of the wider literature we performed a systematic review of the literature(58) to summarize the overall findings for the effect of ultrasound guidance on brachial plexus block. Over the last six years we have moved forward to examine whether ultrasound can reduce common complications of brachial plexus blocks and specifically interscalene block(50, 51).

We explored the possibility of the use of ultrasound for infraclavicular block with a case report(57) and a case series(49) and followed these early case reports with two high quality double-blind, randomized trials. Chan et al(6) randomized 180 patients to either ultrasound, ultrasound + nerve stimulation or nerve stimulation alone for axillary brachial plexus block and remains the largest randomized study comparing ultrasound to existing methods for brachial plexus block. Brull et al(46) examined infraclavicular block in a randomized, double-blind study comparing ultrasound vs dual endpoint nerve stimulation with the primary endpoint of block success 20 minutes after block completion. We then performed a large retrospective review comparing axillary block using ultrasound compared to nerve stimulation and transarterial methods(47). Although this was a retrospective review the study numbers were large enough to demonstrate differences between techniques both with regard to efficacy and adverse effects. We then performed a systematic review of the brachial plexus literature in 2010 examining the impact of ultrasound on efficacy and other outcomes of brachial plexus block. We were not able to perform meta-analysis due to the heterogeneity of different outcomes in each study. The systematic review completed the first stage of research into benefits of ultrasound guidance with most brachial plexus techniques having been subjected to rigorous randomized trials.

In 2007 we started a second phase of investigations into use of ultrasound for brachial plexus block by examining the ability of ultrasound to reduce side effects and complications. An initial simple bench study(48) using a gel phantom and a model of injectate spread in tissue determined that ultrasound could be used to predict local anaesthetic spread and conversely could determine when spread was not visible. The lack of ability to determine local anaesthetic spread is often a sign of misplacement of local anaesthetic such as intravascular injection and may improve the ability of users of ultrasound to avoid intravascular injection and systemic side effects. This has since been demonstrated by Lo et al, Orebaugh et al and Barrington et al(47, 59, 60).
The interscalene technique has many benefits for pain relief after shoulder and upper arm surgery but is contraindicated in those with respiratory impairment because of 100% incidence of ipsilateral phrenic nerve block using standard volumes of local anaesthetic(61). Experience with the use of ultrasound had demonstrated that lower volumes could be used for techniques whilst preserving block success. This may have particular advantage with the interscalene block because of ability to reduce spread to structures where local anaesthetic effect is not wanted. These include the phrenic nerve, the recurrent laryngeal nerve and sympathetic chain. We wanted to evaluate the effect of a low volume interscalene block to determine if we could reduce respiratory complications but preserve block success. In 2008 we performed a randomized study to compare a standard volume (20ml) with a low volume (5ml) of local anaesthetic for ultrasound-guided interscalene block(51). Our primary endpoint was diaphragm paresis 30 minutes after block placement in order to properly investigate the impact of both local anaesthetic volumes on respiratory function. We also measured spirometric variables (FVC, FEV and PEFR) and pulse oximetry in addition to pain and analgesic consumption outcomes for 24h after surgery. We used ultrasound guidance to place the local anaesthetic in both groups. Although we demonstrated a significant reduction in respiratory impairment and no reduction in analgesia with the lower volume one limitation of the study was that we could not compare our results to a non-ultrasound guided method such as nerve stimulation. Therefore although we had demonstrated the success of a low volume technique we could not state that this was directly related to the use of ultrasound.

In order to compare the two nerve location methods of ultrasound and nerve stimulation we designed a further study using the Dixon and Massey Up Down methodology to determine the minimum effective analgesic volume of ropivacaine 0.5% in 50% of patients (MEAV$_{50}$) for each technique. The use of a sequential allocation technique such as the Dixon and Massey technique allows a precise measurement of MEAV$_{50}$ with a smaller sample size than traditionally used in randomized trials. We wanted to compare the difference in precision of ultrasound vs peripheral nerve stimulation and used volume of ropivacaine 0.5% required to produce successful analgesia after shoulder surgery as a measure of proximity to the brachial plexus. Use of the Dixon and Massey method allowed a calculation of MEAV$_{50}$ and a direct comparison between groups.
Studies examining minimum effective volumes of local anaesthetic of other ultrasound guided brachial plexus techniques have calculated MEAV_{50} and then used probit transformation and logistic regression to calculate MEAV_{95}. This method can be inaccurate especially if the 95%CI around the percentile estimate is unacceptably wide. An example of this occurs in the publication by Fredrickson et al(62) where the MEAV_{50} is low (2.7ml) but because of wide confidence intervals the calculated MEAV_{95} is much larger (20.5ml). Other techniques of using sequential allocation to more accurately determine MEAV_{95} include the continual reassessment method (CRM) (63) which has the advantage that any percentile of the dose-response can be estimated including ED_{95}. The CRM has been used with good success recently in regional anaesthesia studies(64).

Summary:

In the last ten years we have taken several different methodological approaches to evaluating the benefit of use of ultrasound for brachial plexus blocks. We started with a high quality randomized study to compare brachial plexus block with general anaesthesia and proceeded to evaluate ultrasound using case reports, case series and a large retrospective cohort study. We performed high quality randomized studies comparing ultrasound with standard of care methods and then performed a systematic review to summarize findings. Finally we used randomized studies to evaluate efficacy and safety of lower volumes of local anaesthetic for interscalene block using ultrasound and then evaluated whether ultrasound might facilitate reduced volumes of local anaesthetic compared to peripheral nerve stimulation methods using sequential dose allocation methods.
Chapter 3: Importance of brachial plexus block and comparison with general anaesthesia for upper extremity surgery


This chapter will review the controversy that existed prior to 2004 about the ideal choice of anaesthetic technique, general anaesthesia or brachial plexus block, for upper extremity surgery. The reasons for the controversy will be further discussed, the evidence for each type of anaesthesia presented and a summary made of the randomised study by McCartney et al (45) that helped to answer the question of superiority between the two techniques. We hypothesized that brachial plexus block would provide significant improvement in pain control and reduction in adverse effects compared to general anaesthesia for ambulatory hand and forearm surgery.

Introduction:

Brachial plexus block has been regarded for many years to provide superior recovery characteristics compared to general anaesthesia for upper limb surgery including better pain control, less sedation and reduction in post-operative nausea and vomiting. However the technique remained underutilized for several reasons including greater familiarity with general anaesthesia techniques and lack of evidence of benefit. With the increase in popularity of day surgery procedures through the 1990s major factors affecting delayed discharge were examined more closely and found to include pain, nausea and vomiting and sedation (52). The realization that local anaesthetic techniques may have greater benefits for the day surgery population was a significant factor in increasing interest in their use.

Until the early 1990s no authors had carefully examined whether brachial plexus block was superior for upper limb surgery. Brown et al (53) and D’Alessio et al (65) produced two early retrospective cohort studies and found that interscalene block had significant advantages for shoulder surgery including better pain control, less nausea and vomiting and sedation. Their findings were undermined by the retrospective methodology and use of general anaesthetic drugs that were not ideal for day surgery including thiopentone for induction, suxamethonium and curare for muscle relaxation and isoflurane for anaesthesia maintenance. In 2001 Chan et al
(54) also examined in a non-randomized study the use of general anaesthesia, brachial plexus block or intravenous regional anaesthesia (IVRA; Bier’s block) for hand surgery. They found that both brachial plexus block and IVRA provided better pain control, less nausea and vomiting and faster discharge eligibility compared to general anaesthesia. This study was limited by the non-randomized nature and the use of isoflurane for general anaesthesia maintenance in the GA group. Unlike previous studies the study was prospectively performed and did use standardized criteria for discharge both from recovery room and day surgery unit and was the best quality data at that time evaluating brachial plexus block compared to GA for upper limb surgery.

Good quality prospective randomized studies had yet to be performed and many practitioners continued to use general anaesthesia techniques for day surgery procedures because of lack of evidence for regional techniques and improvements in pharmacology of anaesthetic agents. These included general anaesthetic drugs with a faster recovery profile and reduced adverse effects compared to older agents such as the volatile agents desflurane and sevoflurane, greater use of shorter acting opioids and non-steroidal anti-inflammatory drugs. In addition use of brachial plexus block and other regional anaesthesia techniques required specialized training, needed greater pre-surgical preparation (in particular to allow block performance and onset time) and continued to be associated with rare but catastrophic complications such as convulsions, cardiac arrest and significant nerve injury. These factors in combination with lack of familiarity of most practitioners with the use of these methods produced a significant barrier to the use of brachial plexus block for upper limb surgery.

After 2003 a series of high quality randomized studies started to demonstrate the benefits of brachial plexus block compared to general anaesthesia for ambulatory upper limb surgery. McCartney et al(45) randomized 100 patients to transarterial brachial plexus block or general anaesthesia for hand surgery and found that patients in the brachial plexus group had faster recovery, reduced pain and requirement for analgesic drugs and less nausea and vomiting compared to general anaesthesia (see table 2). This prospective study also used an intention-to-treat design adding further strength to the results.
Table 2: Early postoperative analgesic consumption and adverse effects from McCartney et al 2004

<table>
<thead>
<tr>
<th></th>
<th>Brachial plexus block group (n=50)</th>
<th>General anaesthesia group (n=50)</th>
<th>Significance (P value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to first analgesic request (min)</td>
<td>97.6 (50.2)</td>
<td>29.9 (22.8)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Intravenous fentanyl in PACU (mcg)</td>
<td>7 (22)</td>
<td>77.5 (50.3)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Oral morphine equivalent in PACU and DSU (mg)</td>
<td>7.3 (15.2)</td>
<td>22.8 (18.1)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Nausea and vomiting in PACU and DSU (no. of patients)</td>
<td>3*</td>
<td>12</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

*Two patients received general anaesthesia for brachial plexus block failure

Hadzic et al (66) randomized 52 patients to either infraclavicular block (ICB) or general anaesthesia for hand and wrist day-case surgical procedures and found that patients having ICB had better pain control, faster ambulation and time to home readiness. In addition patients in the ICB group had fewer adverse events such as nausea, vomiting and sore throat. Hadzic et al (67) performed a further study on 50 patients having outpatient shoulder surgery under either general anaesthesia and wound infiltration or interscalene brachial plexus block (ISB). Patients who received ISB were able to bypass the recovery room more frequently, had less pain and were ready for discharge more quickly than those who had GA. De Windt et al (68) randomised 60 children to either peripheral nerve blocks or opioid analgesia for minor hand surgery. Patients in the peripheral nerve block group had less pain, analgesic consumption, faster time to oral intake and faster discharge after surgery.
Overall the study by McCartney et al(45) was the first prospective randomised study to compare regional vs general anaesthesia for upper limb surgery and remains the largest study of this type. The further studies by Hadzic(66, 67) and De Windt (68) confirmed the initial evidence supporting brachial plexus block. The evidence clearly demonstrates that brachial plexus techniques have superior pain control and recovery characteristics compared to general anaesthesia techniques. Despite that fact brachial plexus blocks retained several limitations including inferior success rate (even in the McCartney study 10% of patients in the brachial plexus block group required general anaesthesia, subjective and difficult to teach endpoints and occasional significant adverse events such as convulsions, persistent paraesthesiae or pain in the axilla. Although brachial plexus techniques had demonstrated significant benefits a method of providing more consistent effectiveness was clearly needed and the use of ultrasound guidance was starting to show promise in that regard.
Chapter 4: Emergence of Ultrasound for Brachial Plexus Localisation

Associated papers:


In 2004 our aims were to evaluate the potential of ultrasound to successfully guide placement of local anaesthetic for brachial plexus block. Although we were using ultrasound for all approaches to the brachial plexus our patient population at that time ensured that a high volume of patients having distal upper limb surgery were seen. We therefore focused our efforts on developing ultrasound approaches to infraclavicular and axillary block. Early experiences helped to develop several hypotheses including:

i) Local anaesthetic spread injected posterior to the axillary artery predicts effective infraclavicular block.

ii) Ultrasound allows successful placement of brachial plexus block when traditional endpoints are not available.

Ultrasound imaging is based on the interpretation of reflected sound waves generated by an ultrasound transducer that has both sound generating (piezoelectric crystals) and receiving components. The sound waves are reflected in a variable manner by tissues through which they pass and the timing of return of the reflected soundwaves generate the ultrasound image seen by the sonographer. Although ultrasound was first developed and used in diagnostic work as early as 1949(69) it was only, because of image quality, used to assess large structures within the abdomen or pelvis. It was long thought that normal peripheral nerves could not be seen with ultrasound(70). However Fornage demonstrated in 1988 with high resolution ultrasound it was possible to identify several peripheral nerves including median, ulnar and sciatic nerve in
the popliteal fossa(38). The first publication in an anaesthesia journal by Ting and Sivagnanaratham(36) was in the British Journal of Anaesthesia in 1989 and documented correct positioning of a cannula in the axilla in 10 patients prior to and after injection of local anaesthetic for axillary brachial plexus block. There was no attempt to visualize local anaesthetic spread at the time of injection although the block was successful in all patients. The first randomised study to examine use of ultrasound for brachial plexus block was by Kapral et al in 1994(37) where he compared supraclavicular and axillary approaches to the brachial plexus using ultrasound in 40 patients. In this study needle tip and local anaesthetic spread was visualized during injection. Perhaps not surprisingly the main findings from this study were that for the axillary approach the block of the musculocutaneous nerve was inconsistent compared with the supraclavicular approach (75% vs 100%). Although this study represented a major advance in ability to perform supraclavicular block as well as axillary block under ultrasound guidance there was no comparison with pre-existing methods of nerve location. Yang et al(40) placed brachial (interscalene and supraclavicular) plexus catheters in 20 adults under sonographic guidance and then demonstrated successful neural blockade in all patients. Until 2002 the infraclavicular brachial plexus block was a technique that required elicitation of distal forearm or hand twitches using electrical nerve stimulation and this was often difficult to obtain. Desroches(71) demonstrated that without a distal twitch the success of infraclavicular block was only 50%. A series of studies demonstrated the benefits of the use of ultrasound for infraclavicular block. Ootaki et al(41) demonstrated successful infraclavicular block using ultrasound in a series of 60 patients under real-time guidance to place the needle and visualise local anaesthetic spread. His results demonstrated a very high rate of success (95-100%) in medial antebrachial cutaneous, musculocutaneous, median, ulnar and radial nerves. Sandhu and Capan(72) also demonstrated a very high rate of success with an ultrasound-guided infraclavicular block in a series of 126 patients having upper limb surgery. They used a three-injection technique at the superior, posterior and inferior aspects of the second part of the axillary artery with only three patients with block failure and nine patients who required supplementation to complete the block. Although these studies demonstrated high success rates with the use of ultrasound they were limited by their methodology as they were only case series without active comparator with other recognised methods of nerve location.

However the utility of ultrasound to guide placement of brachial plexus block was becoming rapidly apparent(73) and we published a series of letters and cases to illustrate this. After
Klaastad et al(74) published details of their nerve stimulator guided lateral and sagittal infraclavicular brachial plexus block we published a letter(57) demonstrating our own technique with the use of ultrasound (see figure 4).

**Figure 4: Ultrasound-guided infraclavicular block.** Short arrow indicates needle. PMJ=pectoralis major, PM=pectoralis minor, LC=lateral cord, PC=posterol cord, A=axillary artery, V=axillary vein, P=pleura. (57)

Further work by our group(49) helped to demonstrate why block failure may occur with the infraclavicular block if only a proximal neuromuscular endpoint (biceps) is obtained with nerve stimulation. In a small series of three patients it was discovered that after biceps stimulation the needle tip often lay too superficial above the clavicular fascia and this prevented adequate spread of local anaesthetic around the three cords of the brachial plexus. Further insertion of the needle to the superior and posterior portion of the 2nd part of the axillary artery allowed spread of local anaesthetic to all three cords and successful block. Furthermore the spread of local anaesthetic when the needle tip was positioned correctly pushed the artery anteriorly. This finding was further confirmed by Dingemans(75) and Bloc et al(76). This series of corrections to
the technique for performing ultrasound-guided infraclavicular block helped to reduce block failure in our hands and encouraged the use of brachial plexus block in patients where previously block would not have been possible. Assmann et al(77) performed a successful ultrasound-guided infraclavicular continuous catheter technique in a female patient with complete forearm amputation who required a reattachment procedure. The absence of a functioning distal limb would have made it impossible to use nerve stimulation to identify correct needle-tip and catheter location. Van Geffen et al(78) performed a series of upper and lower extremity surgical procedures using ultrasound that would have been previously impossible without. One of the cases involved a patient who had an infraclavicular block performed without ultrasound that required supplementation. The use of ultrasound allowed successful supplementation at the infraclavicular level and this would not have been possible with other nerve localization techniques at the infraclavicular level because of ablation of nerve stimulator responses with the prior injection of local anaesthetic.

In summary, over a period of 15 years, the use of ultrasound for brachial plexus block progressed through initial identification of nerves to the first placement of local anaesthetic around the brachial plexus using ultrasound in the supraclavicular and axillary areas. Further work and improvement in quality and portability of ultrasound technology allowed ultrasound to be used for infraclavicular block and fine tuning of existing methods including the use of brachial plexus block in patients where it would not have previously been possible.

Although several groups had accepted ultrasound as an important method for performing brachial plexus block, until 2004 there remained a lack of good quality randomised evidence demonstrating its superiority compared to existing nerve location methods. There was a need for the next stage of investigation to be performed to evaluate the performance of ultrasound compared to the existing gold standard.
Chapter 5: The debate about superiority of ultrasound vs existing nerve location methods for brachial plexus block

Associated papers:


Introduction:

By 2004 several groups had accepted ultrasound as an important method for performing brachial plexus block, however there remained a lack of good quality randomised evidence demonstrating its superiority compared to existing nerve location methods. There was a need for the next stage of investigation to be performed to evaluate the performance of ultrasound compared to the existing gold standard. Our group developed a series of studies to investigate the performance of ultrasound-guided methods compared to existing methods. Specifically we wanted to test the following hypotheses:

i) An ultrasound-guided infraclavicular block provides faster onset compared to a dual–endpoint nerve stimulator guided method.

ii) Ultrasound-guidance improves the success rate of axillary brachial plexus block.

iii) Ultrasound-guidance increases success rate, decreases local anaesthetic volume and reduces complications compared to landmark and nerve stimulator-guided methods.
iv) The sensitivity and specificity of nerve stimulation and paraesthesia techniques are suboptimal when used during axillary brachial plexus block.

v) Ultrasound-guidance provides significant benefits compared to nerve stimulation and landmark techniques when performing brachial plexus block.

_History of nerve location methods:_

The performance of consistent, high quality brachial plexus blocks depends on accurate placement of local anaesthetic around the component nerves of the brachial plexus. The first blocks of nerves of the brachial plexus were performed by Hall and Halstead in 1884 using cocaine(79). Cushing coined the term “regional anesthesia” for his method of direct application of local anesthetic to nerve plexuses under general anesthesia to provide postoperative pain relief. Hirschel developed the “blind” axillary brachial plexus block and Kulenkampff the supraclavicular technique in 1911(11). The spread of regional anesthesia was greatly facilitated by the work of Gaston Labat who taught his techniques to the next generation of anesthesiologists in the United States: John Lundy, Ralph Waters and Emory Rovenstine(80). These pioneers formed the American Society of Regional Anesthesia and created the specialty of Anesthesiology in the 1920’s and 1930’s. However it was not until 1964 and 1970 that Alon Winnie developed methods of performing the interscalene and supraclavicular approaches that revolutionized brachial plexus block(7, 15). These techniques still relied predominantly on anatomical surface landmarks, fascial clicks or paraesthesia techniques that had 70-90% success depending on practitioner.

_The Paraesthesia vs Peripheral Nerve Stimulation Debate:_

Peripheral nerve stimulation to facilitate nerve localization was described in 1912 by Perthes and Greenblatt and Denson also described the method in 1962(81). In 1973 Montgomery et al described their method for the use of peripheral nerve stimulation for a series of peripheral nerve and brachial plexus blocks(82). It was not until the early 1990’s that peripheral nerve stimulation was being used consistently in clinical practice and significant debate continued to rage regarding the superiority of nerve stimulation and paraesthesia techniques(83). Studies that compared paraesthesia against nerve stimulation methods demonstrated similar success rates (70-90%) (29) however some have shown a higher rate of persistent neurological symptoms following paraesthesia(24). Indeed the paraesthesia technique requires very close
approximation of needle tip to nerve and the risk of nerve injury was always a feared complication with the paraesthesia method. This was despite studies that had demonstrated no difference between paraesthesia and nerve stimulation methods(84). Another limitation of the paraesthesia technique is the subjective endpoint requiring patient complaint of paraesthesia in order to confirm correct needle tip placement. This can either lead to false positive (in very anxious patients) or false negative (in oversedated patients) endpoints. One of the reasons nerve stimulation represented a great advance was because patient response was not required to confirm needle tip to nerve proximity.

Limitations of Peripheral Nerve Stimulation and Advent of Ultrasound:

Despite the advances of nerve stimulation the technique had several limitations that limited its use in clinical practice and required a further advance. Nerve stimulation still required the predominant use of surface landmarks for initial needle placement and this could be difficult especially in obese patients. Obtaining a neuromuscular endpoint was sometimes difficult and until the advent of ultrasound imaging the reasons for this were not entirely clear. The variable relationship between nerve stimulation and paraesthesia was investigated by our group (31) and then Urmey et al(30) who scientifically documented what had been clinically suspected: that it is often very difficult to obtain a motor response from nerve stimulation even when the needle tip is close enough to the nerve to elicit paraesthesia. Neal (85) highlighted the level of knowledge at that time in an editorial when he wrote in relation to Choyce et al “Studies such as theirs remind us of how little we understand about the nature of paraesthesiae and the workings of the peripheral nervous system..”. Although nerve stimulation could provide consistent neurolocation information in many patients it was often inconsistent and required significant time to obtain a correct response and in some patients failure to obtain a motor response occurred. Our group performed (34) one of the first studies using ultrasound to further investigate the relationship between needle to nerve proximity, sensory paraesthesiae and ability to elicit a motor response from nerve stimulation. We used ultrasound imaging to direct an insulated needle to contact a nerve (usually median) in the axilla and then patients were asked to report if they perceived paraesthesiae. We then investigated if a motor response could be elicited by nerve stimulation with the needle tip in the same position. Only 38% of patients complained of a paraesthesia when a needle was directly pushed against a nerve as determined by ultrasound visualization. In addition when the nerve stimulator was activated a motor twitch
was only evident in 74.5% of patients at 0.5mA or less. The absence of paraesthesia when direct needle-nerve contact was made and absence of motor twitch with peripheral nerve stimulation at 0.5mA contradicted perceived knowledge at that time but did start to explain why paraesthesia and nerve stimulation endpoints were often technically difficult to obtain. This study also illustrated why the use of ultrasound imaging had great potential for improving the performance of peripheral nerve blocks because needle to nerve proximity could be achieved quickly and direct spread of local anaesthetic observed using the ultrasound image.

**Emerging evidence for the benefit of ultrasound imaging for brachial plexus block:**

More recent studies have continued to demonstrate the difficulty of finding peripheral nerve stimulation endpoints compared to ultrasound methods. We performed a study using interscalene block (50) to compare ultrasound with peripheral nerve stimulation and used the Dixon Massey Up Down Sequential Allocation method to determine MEAV₅₀ for each method. In this study protocol we stipulated, to protect patients from unlimited attempts, that a maximum of 10 needles passes was allowed with either technique to place needle tip in the desired location (adjacent to superior trunk) before reverting to the other method. No patients in the ultrasound group required more than one needle pass. However in the nerve stimulation group the average number of needle passes was three and 35% of patients required to convert from nerve stimulation to US because the correct endpoint was not obtainable within 10 needle passes. Other studies have also demonstrated that ultrasound methods provide significant reduction in time to perform the block compared to nerve stimulation methods(42, 75, 86-88). The first randomized studies comparing ultrasound with existing nerve location techniques were published in 2003 and 2004. Williams et al(42) compared ultrasound and nerve stimulation vs nerve stimulation alone in a randomized but unblinded study in 80 patients using a supraclavicular approach and found the US group had significantly shorter procedure time (5 vs 9.8mins; p=0.0001) compared to PNS. Marhofer et al(89) compared ultrasound to PNS for infraclavicular block in children and found patients in the ultrasound group had less procedure pain, faster block onset (9 vs 15 mins; p<0.001) and duration (384 vs 310 mins; p<0.001). A number of other studies continued to demonstrate the benefits of ultrasound compared to both PNS(75, 88, 90) and landmark methods(87, 91). In 2007 our group(6) published the largest randomized and blinded study to date comparing ultrasound against a group using PNS alone and another group with a combination of ultrasound and PNS for axillary block. The hypothesis
was that the group using both ultrasound and PNS would provide the greatest advantage with regard to performance time, onset time and block success compared to either ultrasound or PNS alone. The primary endpoint was block success as defined by complete sensory block (absence of both pain and touch sensation) in the median, ulnar, radial and musculocutaneous nerves 30 minutes after block completion. The results confirmed that use of ultrasound (either alone or with nerve stimulation) improved block success compared to nerve stimulation alone (82.8%, 80.7% and 62.99% respectively). The study contradicted the perception that combining nerve stimulation with ultrasound would provide a performance advantage because the time to block completion was fastest in the US alone group; 9.3min vs 11.2 (NS alone) and 12.4 (US/NS). In addition patients in the US or US/NS group required less local anaesthetic supplementation and had less post-block axillary bruising and pain. This study both demonstrated that US provided advantages with respect to improving performance time and reducing risk of block failure compared to nerve stimulation. It was one of the first studies to highlight that the use of US and NS together may be a disadvantage compared to US alone with regard to performance time. This may be because when the two techniques are combined practitioners spend time trying to identify motor endpoints despite the visual confirmation using US of needle tip to nerve proximity and may explain the negative results in studies that have compared the combination of ultrasound and nerve stimulation against nerve stimulation alone(92-94).

*Use of ultrasound for infraclavicular block:*

In 2007 despite several studies demonstrating the advantages of ultrasound use for brachial plexus block there remained a need for a high quality study examining the benefits of US for infraclavicular block. Case reports and case series had demonstrated the benefits of US (see chapter 5) and two randomized trials; one in children(89) and one comparing US vs US and NS in adults(92) had been performed. However at that time the “gold standard” for performing infraclavicular block was with nerve stimulation of at least two cords of the brachial plexus(95) and many remained convinced the US method had no advantage compared to this “dual endpoint” technique. We designed a high quality double-blind randomized trial comparing ultrasound against the “dual endpoint” peripheral nerve stimulation method(46). The primary endpoint was defined as block success (loss of pinprick sensation in median, ulnar, radial and musculocutaneous nerve distribution) 20 minutes after block completion. Block success was achieved in 92% of patients in the ultrasound group compared to 80% in the nerve stimulation
group, which did not achieve statistical significance. However several other endpoints are worth
mentioning. In the ultrasound group more patients were ready for surgery after 20 minutes than
patients in the nerve stimulator group (85 vs 65%, 95% CI 2-36% p=0.04). Patients in the nerve
stimulator group required more intraoperative fentanyl for analgesia and the time for block
performance was significantly shorter in the US group (median 5 (IQR 5 min) vs 10.5 mins (IQR
6.8 min) (p<0.001). More patients in the nerve stimulation group complained of unintentional
paraesthesiae during the block (45% vs 6%) and inadvertent vascular puncture also occurred
more commonly in the nerve stimulation group (8% vs 0%). In summary the US infraclavicular
method provided faster block performance, fewer side effects and faster time to surgical
readiness compared to the “dual endpoint” nerve stimulation method.

Use of ultrasound across all brachial plexus techniques:

Subsequently published studies have continued to emphasize the superiority of ultrasound
compared to nerve stimulation across all types of brachial plexus block (58). The one exception is
supraclavicular block where only one randomized study has been performed and a lack of strong
evidence exists (42). This study did show a benefit for US with regard to block performance time
but compared US vs US and PNS and was not blinded.

We performed a systematic review (58) in 2010 and concluded that ultrasound-guided brachial
plexus blocks demonstrate several advantages when compared to preexisting nerve location
methods including faster block onset and greater block success. We have recently completed an
updated review of the same subject area and the results in the last five years have strengthened
overall for ultrasound (McCartney CJ, Choi S. Reg Anesth Pain Med. Submitted) with ultrasound
demonstrating improvements in block performance time, reduced number of needle passes,
incidence of vascular puncture, shortened sensory onset time and improved block success.

Summary:

In the last ten years a series of studies have evaluated the place of ultrasound in the
performance of brachial plexus block. The literature has matured over time with a progression
from early case reports, case series, cohort studies, randomised studies and systematic review
of the literature all demonstrating the superiority of ultrasound guidance over both peripheral
nerve stimulation and landmark techniques for brachial plexus block.
Chapter 6: Literature Review: Ultrasound, Brachial Plexus Block and Local Anaesthetic Volume

Associated papers:


Introduction:

Earlier studies had demonstrated the benefits of ultrasound compared to existing techniques for brachial plexus block but by 2008 preliminary studies had demonstrated that it was possible to reduce local anaesthetic volume whilst preserving success using ultrasound(47). In addition visualization of local anaesthetic spread or its absence could be used as a possible safety marker for correct or incorrect (intravascular or other incorrect) injection. We tested the hypothesis that ultrasound could be used as a test of appropriate local anaesthetic spread(48) and also wrote a commentary on the literature assessing ultrasound and local anaesthetic volume(96).

Background:

Effective brachial plexus block requires accurate placement of sufficient volumes of local anaesthetic to surround components of the plexus and produce rapid onset of sensory and motor block. Practitioners tend to use large volumes of concentrated local anaesthetic to ensure effective block onset and duration. However unintentional intravascular injection or systemic absorption can result in a relatively high incidence of major complications such as seizure or major cardiovascular complications. Most practitioners will use volumes between 20-60ml of local anaesthetic 1-2% for brachial plexus block techniques(17). Typical volumes of local anaesthetic for interscalene block vary from 20-40ml depending on practitioner and indication(19). For supraclavicular and infraclavicular block 30-40ml are typically used(25, 71) and 30-60ml for axillary block(35). Many techniques exceed the recommended maximum doses of local anaesthetic but studies have shown that plasma levels of local anaesthetic do not reach toxic levels even when doses up to 10mg/kg lidocaine are used(97). Despite these large doses of local anaesthetic success rates still remain significantly below 100% for most brachial plexus techniques with success rates of between 70-95% commonly quoted in the literature(17).
Impact of ultrasound on local anaesthetic volume and safety:

Several large cohort studies have also shown that risks of major complications still remain for brachial plexus block but these are being reduced with the use of ultrasound. Our research group (47) examined the records of 662 patients having axillary block between 2003 and 2006 when our institution was transitioning to the use of ultrasound from transarterial axillary block. We found that patients who received ultrasound-guided blocks had higher success rates despite receiving significantly lower volumes of local anaesthetic (39.8+/-6.4ml vs 46.7+/-17.1ml). In addition patients in the ultrasound-group suffered fewer complications (inadvertent intravenous injection and transient neuropathy) compared to the transarterial group. Orebaugh et al(59) performed a retrospective review of >14,000 brachial plexus blocks performed by supervised trainees over a 72-month period. In this study 9062 blocks were performed with combined US and peripheral nerve stimulation (PNS) and 5436 performed with PNS alone. The incidence of local anaesthetic toxicity was significantly increased in the PNS alone group compared to the US and PNS group (0/9062 vs 6/5436 blocks (p=0.0061). Finally Barrington et al(60) examined outcomes after 7434 brachial plexus blocks and found 13 episodes of local anaesthetic toxicity (incidence 0.21% for non-ultrasound and 0.059% for ultrasound techniques; p=0.004).

Ultrasound reduced the incidence of both minor and major local anaesthetic systemic toxicity. Local anaesthetic spread is evident during correct placement and this may help to prevent unintentional intravascular injection. We tested the hypothesis that practitioners could distinguish between successful local anaesthetic spread and intravascular injection in a bench model(48). In this model the sensitivity and specificity of determining correct local anaesthetic spread was high using ultrasound and this may be a factor in prevention of intravascular injection.
Table 3: Sensitivity and specificity of ability to detect injectate spread using ultrasound(48)

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<th></th>
<th>Novices</th>
<th>Experts</th>
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<td>Negative Predictive Value</td>
<td>0.87</td>
<td>0.92</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

As mentioned one of the advantages of ultrasound is that local anaesthetic spread can be seen and it is possible to obtain similar success with lower volumes of local anaesthetic(51). In fact animal studies have demonstrated that much smaller doses of local anaesthetic than those used clinically in humans are required to block nerve conduction. Models have demonstrated that only 1.6% of the total injected volume of local anaesthetic is required for nerve block with only 0.02% lidocaine concentration required within the nerve(98).

Thirty years ago, prior to the use of ultrasound Vester-Andersen and colleagues examined the effect of varying concentration and volume for brachial plexus block in a series of studies using a perivascular axillary block technique(35, 99-102). They found that the ideal volume to ensure reliable axillary block was 50ml and that although increasing concentration from 0.5 to 1.5% mepivacaine improved motor block it had no effect on sensory block. Until the advent of ultrasound, volumes and doses of local anaesthetic used for brachial plexus block remained high. Some practitioners had started to advocate lower volumes for interscalene block especially when only shoulder analgesia was required after arthroscopic surgery. For example Chan et al (103, 104)produced a series of studies using 10ml of varying concentrations of bupivacaine and ropivacaine and demonstrated successful analgesia with this volume using a peripheral nerve stimulator-guided method. However until ultrasound became available the definition of low
volume was still anything >10ml and until very recently up to 65ml was used for interscalene block in one institution(105).

Recent studies examining volume of local anaesthetic required for ultrasound-guided brachial plexus block:

In the last five years a series of articles have evaluated whether it is possible to maintain brachial plexus block success whilst using lower volumes of local anaesthetic using ultrasound-guided techniques. McNaught et al(50, 51), Gautier et al(106) and others have taken this further with interscalene block to evaluate whether reducing volume can also reduce common side effects and complications (see chapter 8).

Harper et al(107) performed a pilot study on 19 patients to determine the minimum volume of local anaesthetic required to surround each of the constituent nerves of the axillary brachial plexus and found that 2-4 ml of local anaesthetic per nerve was sufficient to successfully perform the block. A similar study (108) was performed in volunteers to examine the minimum volume of local anaesthetic required to block the ulnar nerve in the forearm guided by ultrasound. They found that the ED95 to effectively block the ulnar nerve in the forearm using mepivacaine 1% was 0.7ml.

O’Donnell et al then performed a study in patients using up-down methodology to examine the MEAV50 of lidocaine 2% with 1:200,000 epinephrine for ultrasound-guided axillary block(109). The authors started the study using 4ml per nerve and increased or decreased volume of local anaesthetic by 0.5ml with each successive success or failure. An a priori stopping rule of 5 successful blocks was also included. The study was stopped after 11 patients because 5 consecutive patients had successful blocks using 1ml of local anaesthetic per nerve. O’Donnell subsequently examined the duration of this low volume of local anaesthetic and found durations that are commonly seen with standard volumes(110). Similarly low volumes of local anaesthetic were demonstrated to be effective for interscalene block by our group(50). Using an up-down methodology to examine MEAV50 of ropivacaine 0.5% we determined that the MEAV50 to provide successful postoperative analgesia for shoulder surgery was only 0.8ml using ultrasound.

Other authors have examined MEAV for infraclavicular and supraclavicular block. De Tran et al (111)examined the MEAV50 for infraclavicular block with lidocaine 1.5% with epinephrine and
determined that the MEAV$_{90}$ was 35ml (95% CI 30-37.5ml). These authors also examined supraclavicular block(112) using the same methodology and found that the MEAV$_{90}$ was 32ml (95% CI 30-34ml). Duggan et al(113) examined ultrasound guided supraclavicular block and estimated the MEAV$_{90}$ volume to be 42ml. Pavacic Saric et al(114) examined the MEAV$_{90}$ for supraclavicular block and investigated whether a difference existed between middle-aged (<50) and elderly (>65) patients. They found that the MEAV$_{90}$ was significantly lower in the elderly group (11.9ml) compared to 23ml in the middle-aged group.

To summarize, in order to anaesthetize much smaller brachial plexus targets such as the superior trunk (interscalene block) or terminal nerves of the brachial plexus (axillary block) much smaller volumes of local anaesthetic appear to produce successful block. However with larger plexuses of nerves such as the supraclavicular or infraclavicular brachial plexus larger volumes of local anaesthetic are necessary to ensure success. These volumes actually approach and exceed volumes traditionally used prior to ultrasound(113) and negate the benefit of ultrasound in terms of any dose reduction. However in comparative studies of ultrasound vs pre-existing techniques for supraclavicular and infraclavicular block other advantages such as faster block onset and greater efficacy have been observed(58).

**Volume of local anaesthetic and block duration:**

A final discussion needs to be had regarding duration of anaesthesia and analgesia especially with reduced volumes of local anaesthetic and this has been addressed in a recent editorial (96). A criticism of using lower doses of local anaesthetic than previously recommended is that although block onset is not affected, duration of anaesthesia and analgesia may be reduced. Early studies by O’Donnell and Riazi suggested that reduction in volume did not have impact on block duration(51, 110). However there have been two recent reports suggesting that duration may be adversely impacted by reducing volume of local anaesthetic. Schoenmakers et al(115) compared 15 to 40ml of mepivacaine 1.5% for ultrasound-guided axillary block (3-4ml or 10ml around the median, ulnar, radial and musculocutaneous nerve). In the low volume group 13% of patients required local anaesthetic rescue compared to 0% in the high volume group. Sensory and motor block onset was identical in the remaining patients but duration of sensory block was shorter in the patients who had a low volume technique (225 (148-265) vs 271 (240-401) min; p<0.001). Fredrickson et al(116) compared a low volume (16ml) ultrasound-guided ankle block with a group having 30ml of ropivacaine 0.5% and although block success was greater in the low
volume group pain was worse in the first 24h after surgery suggesting that the sensory block was shorter in the low volume group.

Although early studies indicate that low volumes of local anaesthetic can be used successfully with similar block efficacy and duration these two further studies raise questions that need to be answered by further randomized trials. It is highly likely that the characteristics that affect block onset and duration differ markedly by site of administration. For example volumes of local anaesthetic required to provide successful block for a small target such as the superior trunk during interscalene block are markedly different from the volumes required to perform plexus techniques such as supraclavicular and infraclavicular blocks. We also do not know if the characteristics of onset and duration are affected by volume, concentration or total dose for brachial plexus blocks.

**Summary:**

The use of ultrasound has allowed practitioners to use lower volumes of local anaesthetic for brachial plexus block whilst maintaining success. Furthermore, use of ultrasound has in a number of cohort studies demonstrated a reduction in accidental systemic injection of local anaesthetic and subsequent risk of central and cardiovascular complications. Studies have demonstrated that very low volumes can be used successfully for interscalene, axillary and forearm blocks however duration of anaesthesia and analgesia may be adversely affected. Further research is required to determine ideal volume, concentration or dose of local anaesthetic for each approach to the brachial plexus with ultrasound with regard to optimizing onset and duration of block(96).
Chapter 7: Ultrasound, volume and interscalene block

Associated papers:


Introduction:

Visualisation of local anaesthetic spread around target nerve structures using ultrasound guidance had given practitioners confidence to reduce local anaesthetic volume. Interscalene block provides profound analgesia of the shoulder and upper arm but is associated with 100% phrenic nerve block at standard volumes of local anaesthetic. This contraindicates the use of this technique in patients with respiratory compromise. A small pilot series of patients had demonstrated that 5ml of ropivacaine 0.5% used for interscalene block had provided similar duration of analgesia compared to standard (20ml) volumes. In an initial study we hypothesized that much smaller volumes (5ml) of local anaesthetic could both reduce phrenic block and maintain duration of analgesia when used for ultrasound-guided interscalene block. In a further study we hypothesized that ultrasound-guided interscalene block would require significantly lower volumes of local anaesthetic compared to nerve stimulator guided block to provide effective analgesia after arthroscopic shoulder surgery.

Background:

Interscalene block (ISB) is a reliable analgesic and anaesthetic technique for shoulder and upper arm surgery. Traditionally, 15-40ml of local anaesthetic has been used for ISB but systemic toxicity causing loss of consciousness and seizures can occur with these volumes if unintentional intravascular injection occurs(19). Proximal spread to the cervical plexus (C3-4) and anterior spread to the cervical sympathetic chain and recurrent laryngeal nerve can result in Horner’s syndrome and hoarseness. More importantly, ipsilateral hemi-diaphragmatic paresis from phrenic nerve palsy occurs in 100% of cases at traditional volumes(19) due to the close
proximity of the phrenic nerve (C3-5). This hemidiaphragmatic paresis results in a 30%-40% reduction in pulmonary function(117) and contraindicates the use of this technique in patients with limited pulmonary reserve such as those with chronic obstructive pulmonary disease, significant obesity or the elderly. Use of the block in this population can result in hypoxia and potential requirement for respiratory support. Unfortunately, this limitation precludes the use of this block in the very population of patients who have most to benefit from the reduced opioid consumption and avoidance of general anaesthesia that interscalene block can provide.

*Impact of ultrasound on performance of interscalene block:*

Recent advances in performance of brachial plexus blocks with ultrasound have allowed reduction in local anaesthetic volumes whilst preserving block success (see chapter 7). The reduction in local anaesthetic volume may allow reduction in spread to other important structures such as phrenic nerve, recurrent laryngeal nerve and sympathetic chain and hence reduction in complications/adverse effects associated with blockade of those structures.

In the last six years our group and others around the world have investigated whether it is possible to reduce volume of local anaesthetic for interscalene block and reduce incidence of complications whilst preserving block success (table 4).
Table 4: Characteristics of studies examining ultrasound-guided interscalene block and volume

<table>
<thead>
<tr>
<th>Studies</th>
<th>Study Type</th>
<th>Block Details</th>
<th>Surgery</th>
<th>N</th>
<th>Vol (ml)</th>
<th>Conc (%)</th>
<th>Respiratory impairment</th>
<th>Block Success (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vandepitte</td>
<td>D/M</td>
<td>Injection through interscalene catheter</td>
<td>Arthroscopic shoulder</td>
<td>29</td>
<td>7</td>
<td>Ropivacaine 0.75%</td>
<td>Not measured</td>
<td>MEAV&lt;sub&gt;95&lt;/sub&gt;</td>
</tr>
<tr>
<td>2013</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Falcao</td>
<td>D/M</td>
<td>Multiple injection at upper/middle and middle/lower trunk 1 operator</td>
<td>Shoulder: open and arthroscopic</td>
<td>25</td>
<td>0.95</td>
<td>Bupivacaine 0.5</td>
<td>No impairment below 4.3ml</td>
<td>MEAV&lt;sub&gt;90&lt;/sub&gt;</td>
</tr>
<tr>
<td>2012</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fredrickson</td>
<td>RCT</td>
<td>Single injection at C5-6 through catheter</td>
<td>Shoulder: open and arthroscopic</td>
<td>40</td>
<td>5</td>
<td>Ropivacaine 0.75%</td>
<td>Not measured</td>
<td>70</td>
</tr>
<tr>
<td>2012</td>
<td></td>
<td>Cervical plexus block 2 operators</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gautier</td>
<td>D/M</td>
<td>Multiple injection at superior, middle and inferior trunk 2 operators</td>
<td>Shoulder: open and arthroscopic</td>
<td>20</td>
<td>5</td>
<td>Ropivacaine 0.75%</td>
<td>Not measured</td>
<td>MEAV&lt;sub&gt;95&lt;/sub&gt;</td>
</tr>
<tr>
<td>2011</td>
<td></td>
<td>Multiple injection at C5-6 before catheter placed 2 operators</td>
<td>Shoulder: open</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lee</td>
<td>RCT</td>
<td>Single injection C5-6</td>
<td>Shoulder: arthroscopic</td>
<td>31</td>
<td>5 vs 10</td>
<td>Ropivacaine 0.75%</td>
<td>33% vs 60% diaphragm paralysis</td>
<td>100</td>
</tr>
<tr>
<td>2011</td>
<td></td>
<td>Single operator</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>McNaught</td>
<td>RCT</td>
<td>Single injection at C5-6</td>
<td>Shoulder: arthroscopic</td>
<td>21</td>
<td>0.9 vs 5.4</td>
<td>Ropivacaine 0.5</td>
<td>Not measured</td>
<td>MEAV&lt;sub&gt;50&lt;/sub&gt;</td>
</tr>
<tr>
<td>2011</td>
<td></td>
<td>Portal infiltration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sinha</td>
<td>RCT</td>
<td>Single injection at C5-6</td>
<td>Shoulder: arthroscopic</td>
<td>30</td>
<td>10 vs 20</td>
<td>Ropivacaine 0.5</td>
<td>No difference</td>
<td>100</td>
</tr>
<tr>
<td>2011</td>
<td></td>
<td>Portal infiltration</td>
<td></td>
<td></td>
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</table>
Early studies using peripheral nerve stimulation had demonstrated that good postoperative analgesia is possible with volumes as low as 10ml of ropivacaine 0.25-0.5%(103). We hypothesized that lower volumes would be possible and designed a randomized study to investigate if lower volumes (5ml) could be successful whilst avoiding respiratory and other complications of interscalene block. This study (51) was the first randomized study to investigate whether lower volumes of local anaesthetic have an effect on interscalene block efficacy and duration. We randomized 40 patients to either a high (20ml) or low (5ml) volume of local anaesthetic for patients having arthroscopic shoulder surgery under general anaesthesia. The primary outcome was diaphragmatic movement as measured by ultrasound 30 minutes after block performance and secondary outcomes included pain up to 24h after surgery, analgesic consumption and spirometric variables. The incidence of diaphragmatic paralysis was significantly lower in the low volume group (45 vs 100%) and reduction in spirometric variables was also significantly lower in the low volume group. There were no differences in pain scores,
sleep quality and analgesic consumption up to 24h after surgery. This preliminary small study suggested that local anaesthetic volume could be significantly reduced whilst both maintaining success and reducing respiratory complications of interscalene block. Our group further examined (50) whether ultrasound could reduce required local anaesthetic volume for interscalene block as compared against nerve stimulation in a randomized study using the Dixon and Massey up and down methodology. We found that the MEAV\textsubscript{50} of ropivacaine 0.5% using ultrasound was 0.9ml (95% confidence interval 0.3-2.8) compared to 5.4ml (95% CI 3.4-8.6) in the nerve stimulation group. Furthermore ultrasound significantly reduced the number of needle passes required to identify the brachial plexus (1 vs 3; p<0.0001) and patients in the ultrasound group had less pain 30 minutes after surgery. This study directly compared ultrasound against nerve stimulation and found that for interscalene block ultrasound reduced local anaesthetic volume, number of required attempts and postoperative pain compared to peripheral nerve stimulation.

Renes et al(118) also used a Dixon and Massey up-and-down design to determine the MEAV\textsubscript{50} of ropivacaine 0.75% for interscalene block at the C7 root level and found that the MEAV\textsubscript{50} was 2.9ml (95% CI2.4-3.5ml) and calculated MEAV\textsubscript{95} was 3.6ml (95% CI 3.3-6.2ml). At that volume they found that ventilatory function and diaphragmatic movement was not reduced up to 2h after surgery. Several other studies have looked at the ideal volume of local anaesthetic for interscalene block and subsequent effect on ventilatory function. Lee et al(119) compared 5 vs 10ml ropivacaine 0.75% in a randomized blinded study and examined time to first analgesic request, pain scores, hemidiaphragmatic paresis and other block-related complications. They found that there was no difference in time to first analgesic requirement (16 vs 18h) and pain scores were similar in both groups. Postoperative hemidiaphragmatic paresis (as measured by chest x-ray) was 33% in the 5ml and 60% in the 10ml group. Conversely Sinha et al(120) compared 10 vs 20ml of ropivacaine 0.5% and found a decrease in hemidiaphragmatic paresis and pulmonary function in both groups but no difference between groups. Gautier et al(106) examined the MEAV for interscalene block using ropivacaine 0.75% and found that 5ml (approximately 1.5ml per nerve root) was effective with a median block duration of 9.9 (5-19) hours. Finally, Falcao et al(121) determined the MEAV\textsubscript{50} for bupivacaine 0.5% with epinephrine for interscalene block and examined both postoperative analgesia and ventilatory function. They found that the MEAV\textsubscript{50} was 0.95ml (very similar to McNaught et al) and that the maximum volume that did not cause diaphragmatic block was 4.29ml. MEAV\textsubscript{50} for postoperative analgesia...
(absence of pain and no analgesic use for 6h after surgery) was determined to be 2.34ml (95%CI 0.48-11.47ml).

In summary, for single injection interscalene block it appears that volumes as low as 0.9ml can produce effective postoperative analgesia. Effective duration of postoperative analgesia can be produced with volumes as low as 2.34ml. It also appears that volumes at or greater than 10ml of local anaesthetic tend to produce a high incidence of diaphragmatic paresis. Practitioners who wish to provide effective analgesia with interscalene block but limit any respiratory impairment should use volumes at or less than 5ml.

**Effect of ultrasound on volume for continuous interscalene block:**

Although volumes for effective single injection interscalene block (through the needle) appear to be at or below 5ml many practitioners are now also using continuous interscalene catheters to prolong postoperative analgesia. The volume both to institute and maintain effective interscalene block and postoperative analgesia may be different when local anaesthetic is injected through the catheter and several studies have now examined this question. Fredrickson et al performed two studies examining the effect of concentration and volume of local anaesthetic for institution of interscalene catheter analgesia. Firstly he examined the MEAV$_{50}$ of ropivacaine 0.5% injected through an interscalene catheter with a primary endpoint of presence/absence of recovery room pain[62]. He found that the MEAV$_{50}$ was 2.7ml (95% CI 2.4-9.5ml) but a calculated MEAV$_{95}$ found a much greater volume of 20.5ml (95%CI 17.3-25.8ml). He then performed a further study [122] to examine effect of volume and concentration on interscalene catheter analgesic duration and found that at a 20ml volume increasing concentration of ropivacaine from 0.375% to 0.75% increased duration of primary block from 10.75 to 13.75h. Vandepitte et al [123] also examined the MEAV$_{95}$ for ropivacaine 0.75% when injected through an interscalene catheter to institute effective block. In contrast to Fredrickson the MEAV$_{95}$ was found to be 7ml (95%CI 6.8-7.2ml) but with a median block duration of 8.9h (3-15h). The contrast between the results of Fredrickson and those of Vandepitte deserve further discussion because a large difference in volume for MEAV$_{95}$ was observed. In the Vandepitte study the technique used to place the catheter involved placing the needle between the middle and superior trunks of the brachial plexus and the catheter was advanced only 1cm past the needle tip. In the Fredrickson study the needle tip was positioned lateral to the two most superficial elements of the brachial plexus (C5 and C6) and the catheter inserted 2cm past the
needle tip after bolus of 10ml of dextrose 5%. This difference in technique may have resulted in different estimates of MEAV<sub>95</sub>. In addition the method to calculate MEAV<sub>95</sub> differed between studies. In the Fredrickson study an isotonic regression technique was used to calculate MEAV<sub>95</sub> from the MEAV<sub>50</sub>. This method can be inaccurate especially if the 95%CI around the percentile estimate is unacceptably wide which at 7ml in the Fredrickson study may have been the case. In the Vandepitte study a continual reassessment method (CRM) was used to calculate MEAV<sub>95</sub>. The CRM may allow for a more accurate estimate of MEAV<sub>95</sub> because it has the ability to “learn” from data gathered at earlier time points in the study(63). The wide differences between these two studies indicate that further research is required to fully answer questions around ideal volume for use when instituting interscalene block through a catheter. In addition neither study examined respiratory effects of interscalene catheter use.

*Continuous interscalene block and respiratory impairment:*

Only two studies have assessed respiratory impairment with the use of continuous interscalene block after shoulder surgery. Prior to the use of ultrasound Borgeat et al(124) examined respiratory function for patients who either had continuous interscalene analgesia with ropivacaine 0.2% or patient-controlled intravenous analgesia for 48h after shoulder surgery and demonstrated no difference in respiratory impairment between groups but superior analgesia in the PCIA group. As part of the study examining volume for interscalene block Renes et al(118) placed interscalene catheters using ultrasound at the C7 level for analgesia after shoulder surgery and used ropivacaine 0.2% 6ml/h for postoperative continuous interscalene analgesia. Although ventilatory function and diaphragm movement was not affected up to 2h after surgery by 24h ventilatory function and diaphragm movement were significantly reduced (p<0.001).

*Summary:*

For postoperative analgesia using single-injection ultrasound-guided interscalene techniques local anaesthetic volumes as low as 1ml can produce effective postoperative analgesia(50). However to ensure reasonable duration of analgesia volumes >2.5ml are needed(121) but <5ml should be injected to reduce degree and duration of respiratory impairment(51, 120).

For continuous interscalene block a primary bolus of 7ml is required to ensure adequate postoperative analgesia(123).
Despite ultrasound placement and use of lower volumes at the present time it appears that using a continuous interscalene infusion will cause respiratory impairment even if immediate postoperative respiratory function is normal\(^{(118)}\). However further work is required to confirm initial findings and also to compare with the respiratory effects of alternative methods of analgesia. Borgeat et al\(^{(124)}\) demonstrated that no difference exists between patient controlled continuous interscalene analgesia and intravenous patient controlled opioid with regard to degree of respiratory impairment underlining the respiratory depressant effect of opioid analgesics.
Chapter 8: Future Directions:

Introduction:

In the last ten years brachial plexus block techniques have demonstrated superiority compared to general anesthesia for upper extremity surgery with improved pain control, reduced adverse effects and faster discharge (125). Ultrasound guidance has progressed from demonstrating feasibility to evidence of superior efficacy compared to existing techniques (58). In the last few years ultrasound has been demonstrated to reduce adverse effects and complications for patients having brachial plexus block compared to pre-existing methods such as landmark techniques and peripheral nerve stimulation (47, 59, 60).

Although the question of superiority regarding most ultrasound-guided brachial plexus techniques has been addressed a number of questions remain to be answered. Ultrasound-guided supraclavicular block has only been examined in one unblinded randomised study where nerve stimulation was used in both groups (42) and would warrant further investigation. Although many studies have been performed evaluating the performance of ultrasound-guided techniques there has been only preliminary studies evaluating how best to teach these new techniques. Further studies determining ideal doses of local anaesthetics for brachial plexus block (to ensure both fast onset and duration) are also required. Although many of these studies were performed in the past they were done prior to the use of ultrasound. There are also interesting newer technologies being developed that may improve learning of ultrasound-guided brachial plexus techniques and need to be further examined. Finally, newer methods of extending duration of brachial plexus anaesthesia including catheter techniques, liposomal local anaesthetic preparations and analgesic adjuvants that can extend duration of brachial plexus blocks need to be further evaluated.

Teaching ultrasound-guided brachial plexus block:

Although there are now many studies demonstrating that ultrasound improves several aspects of block performance compared to nerve stimulation or landmark techniques there are few studies examining how best to teach these methods or determining the learning curve for trainees with ultrasound methods. A scoping review of the literature from our group (126) determined that only preliminary studies exist for evaluating motor skills, learning anatomy and determining best structure for an ultrasound-guided regional anaesthesia education program.
and that much work remains to be done. Several groups around the world are now actively investigating this area including groups in Cork in Ireland, Melbourne in Australia and Toronto in Canada (127-129). New technologies allowing simulation with haptic feedback (130) and needle guidance methods for performing ultrasound-guided techniques (131) potentially offer exciting methods of shortening or reducing the required number of blocks to achieve competence. All of these technologies will require further examination in appropriately designed studies to determine their utility and cost-effectiveness.

Dose and volume of local anaesthetics using ultrasound:

Although studies have been performed examining required volumes of local anaesthetic for onset of all approaches to the brachial plexus (see chapter 7) few studies have been performed to examine relationship between dose and volume and relationship between dose, volume and duration(96). Some of the studies that have been performed are discussed in chapters 7 and 8 but much work remains to be done. There is some evidence for some blocks that duration is preserved with lower volumes (51, 110) but other studies demonstrating decrease in duration with much lower volumes(115, 116). It is not currently known if this is related to location, volume, concentration, dose or type of local anaesthetic. In addition we do not know if analgesic adjuvants such as tramadol, buprenorphine or dexamethasone (132) have any impact on duration at lower volumes. A low volume (or dose) technique that produces effective anaesthesia, prolonged analgesia and minimizes risk of adverse effects would be ideal especially if this could avoid the need for the technically difficulty and workload implications of the use of continuous peripheral nerve blocks.

For interscalene block several questions remain to be answered. Although Gautier et al(106)
examined the minimal effective anaesthetic volume for interscalene block they did not investigate volumes less than 5ml. This is possibly an artificially high volume of local anaesthetic and we are currently examining the MEAV₉₅ of ropivacaine 0.75% using a biased-coin design to re-examine this question. We also currently do not know the ideal site of placement, local anaesthetic volume, concentration or dose for patient controlled continuous interscalene analgesia after shoulder surgery to both optimize postoperative analgesia and reduce risk of respiratory impairment. Further studies need to be performed to answer these questions.
Summary:

In the last ten years much work has demonstrated the improved effectiveness and safety of ultrasound-guided brachial plexus blocks compared to pre-existing methods such as nerve stimulation and landmark methods. Much work remains to be performed examining methods of teaching ultrasound-guided techniques, determining ideal volume and concentration of local anaesthetics for each approach to the brachial plexus with ultrasound and the role of new local anaesthetic preparations and adjuvants in prolonging duration of brachial plexus block.
Chapter 9: Overall conclusions from the program of work

In 2002-2003 when we designed the first study related to this thesis (45), brachial plexus block was a technique with an unproven case for superiority compared to general anaesthesia and the success rate of many brachial plexus techniques was only in the 50-80% range (17). In addition the use of ultrasound for brachial plexus block was relatively untried (133).

The enclosed program of research represents the results of 10 years of study of outcomes related to clinical performance of brachial plexus anaesthesia. We examined and demonstrated superiority of brachial plexus block compared to general anaesthesia for upper limb surgery (45). We then examined the feasibility, efficacy and safety of use of ultrasound guided techniques for brachial plexus block in a series of papers that used several different types of methodology including case reports (57, 77), case series (49, 78), randomized trials (6, 46, 50, 51), case cohorts (47) and systematic review of the literature (58). We have also evaluated the sensitivity and specificity of nerve stimulation, paraesthesia methods and ultrasound endpoints in two further studies related to brachial plexus block (34, 48). All studies within this submission relate to evaluating and optimizing the practice of brachial plexus anaesthesia.

The randomized trial by McCartney et al (45) remains the largest randomized study comparing brachial plexus block vs general anaesthesia for upper limb surgery and was one of three randomized studies published in 2004 and 2005 to demonstrate the superiority of brachial plexus block (45, 66, 67). This study has been followed by several others also demonstrating the benefits of peripheral nerve blocks for upper and lower extremity surgery (125) but remains the largest to date.

The case reports and case series published between 2004 and 2007 were the first published cases evaluating ultrasound for varying brachial plexus block procedures or for indications where previous nerve location methods would not have been possible (49, 57, 77, 78). The Porter et al series helped to shape our own subsequent randomized trial (46) but the success of the technique of placing local anaesthetic posterior to the second part of the axillary artery was subsequently confirmed in further papers by Bloc (76) and Dingemans (75).

The randomised study by Chan et al (6) remains the largest randomised study comparing nerve stimulation with ultrasound for brachial plexus block and led to a further understanding of the
relationship between using ultrasound alone and the addition of nerve stimulation with ultrasound. It has been cited on 271 occasions (Google scholar) since publication.

The study by Perlas et al (34) was the first to study the relationship of paraesthesia to nerve stimulation endpoints as evaluated by ultrasound and added to previous data by Choyce et al (31) and Urmey et al (30). In addition it prompted a series of animal studies to further investigate the relationship between nerve stimulation and intraneural needle placement and subsequent possible nerve injury (134-136).

Lo et al (47) was the first large cohort study to examine outcomes related to ultrasound-guided techniques in relation to a change in practice from landmark and nerve stimulation methods to ultrasound. In addition to demonstrating greater block success using ultrasound this was the first to demonstrate improvement in safety (less accidental intravenous injection and transient neuropathy) compared to prior to use of ultrasound. Subsequent large cohort studies have continued to demonstrate both efficacy and safety benefits to the use of ultrasound guidance (59, 60, 137).

Riazi et al performed a study evaluating a low volume (5ml) of local anaesthetic for interscalene block that was, at that time, the first to demonstrate advantages with regard to reduction in complications but with preserved efficacy compared to standard volume (20ml) techniques. This study has been replicated by other studies to examine impact of different volumes of local anaesthetic on respiratory function after interscalene block. Smith et al (138) also used the data from this study to allow the safe use of low volume interscalene blocks on patients with traditional contraindications to interscalene block. McNaught et al (50) performed a follow-up study comparing nerve stimulation vs ultrasound using up-down sequential allocation methodology and is the only study to date comparing ultrasound against nerve stimulation using this methodology. The required volumes of local anaesthetic were surprisingly low in this study but other authors have since replicated these findings for interscalene block (106, 121).

In the last ten years the cases and studies described within this thesis have demonstrated that brachial plexus block is a superior anaesthetic technique for upper limb surgery and that ultrasound improves brachial plexus block success and safety. For interscalene block ultrasound reduces volumes of local anaesthetic required for success whilst also reducing respiratory and other complications.
Chapter 10: Bibliography:

79. Halsted W. Practical comments on the use and abuse of cocaine; suggested by its invariably successful employment in more than a thousand minor surgical operations. NY Med J. 1885;42:294-5.
## Appendix 1: Contributions made to each paper included in the thesis:

<table>
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<tr>
<th>Paper</th>
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<th>Data</th>
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Guidelines for authorship:

- **C/D**: Concept/Design
- **Data**: data collection
- **D/R**: drafting/revision
- **FA**: Final approval
- **PA**: principal author
- **GF**: grant funded
- **Pl**: PI on grant

All authors included in the submitted studies have agreed with the contributions listed above (see email attachment below).
Appendix 2: Papers presented
Early but No Long-term Benefit of Regional Compared with General Anesthesia for Ambulatory Hand Surgery


Background: The purpose of this study was to determine whether either regional anesthesia (RA) or general anesthesia (GA) provided the best analgesia with the fewest adverse effects up to 2 weeks after ambulatory hand surgery.

Methods: Patients undergoing ambulatory hand surgery were randomly assigned to RA (axillary brachial plexus block; n = 50) or GA (n = 50). Before surgery, all patients rated their hand pain (visual analog scale) and pain-related disability (Pain-Disability Index). After surgery, eligibility for bypassing the post-anesthesia care unit (“fast track”) was determined, and pain, adverse effects, and home-readiness scores were measured. On postoperative days 1, 7, and 14, patients documented their pain, opioid consumption, adverse effects, Pain-Disability Index, and satisfaction.

Results: More RA patients were fast-track eligible (P < 0.001), whereas duration of stay in the postanesthesia care unit was shorter in the RA group (P < 0.001). Time to first analgesic request was longer in the RA group (P < 0.001), and opioid consumption was reduced before discharge (P < 0.001). In the RA group, the pain ratings measured at 30, 60, 90, and 120 min after surgery were lower (P < 0.001), and patients spent less time in the hospital after surgery (P < 0.001). More GA patients experienced nausea/vomiting during recovery in the hospital (P < 0.05). However, on postoperative days 1, 7, and 14, there were no differences in pain, opioid consumption, adverse effects, Pain-Disability Index, or satisfaction.

Conclusions: Despite significant reduction in pain before discharge from the hospital after ambulatory hand surgery, single-shot axillary brachial plexus block does not reduce pain at home on postoperative day 1 or up to 14 days after surgery when compared with GA. However, RA does provide other significant early benefits, including reduction in nausea and faster discharge from the hospital.

Both regional anesthesia (RA) and general anesthesia (GA) are commonly performed for ambulatory hand surgery. Existing nonrandomized prospective and retrospective data show that RA offers several advantages compared with GA during recovery in the hospital after ambulatory hand surgery, including a reduction in opioid and antiemetic consumption, shortened duration of stay in the postanesthesia care unit (PACU) and day surgery unit (DSU), and expedited discharge from the hospital. Compared with GA for ambulatory surgery of the upper limb, RA is associated with reduced surgical and nonsurgical intraoperative times, fewer unanticipated postoperative hospital admissions, and greater patient satisfaction. In addition, the complete sensory blockade produced by RA techniques may reduce central sensitization and may have a preventive analgesic benefit.

However, modern general anesthetic and analgesic techniques have several advantages compared with older agents and may negate any advantage of RA. Newer short-acting general anesthetic agents produce significantly fewer adverse effects, shorter recovery time, reduced hospital costs, and improved patient satisfaction compared with older agents. Anesthesiologists are more familiar with providing GA compared with RA, and it follows that GA is the most widely used anesthetic technique for ambulatory surgery.

Although RA has been associated with improved outcomes for patients undergoing hand surgery while they are in the hospital, less is known about what happens after discharge. Cooperation with rehabilitation is important for functional success after surgery, and good early pain control may facilitate this process.

No previous prospective randomized trials exist to determine whether RA or GA is superior for patients undergoing ambulatory surgery of the upper extremity. Our hypothesis was that RA, by providing good early pain control, would provide patients with better pain control and less pain-related disability at 14 days after surgery.

Materials and Methods

After approval by the University Health Network Research Ethics Board (Toronto, Canada) and written informed consent, we recruited patients with American Society of Anesthesiologists grade I–III who were undergoing ambulatory hand surgery to this prospective, ran-
domized, open-label study. Inclusion criteria included age 18–80 yr, weight 40–100 kg, and surgery duration greater than 30 min and less then 3 h. Exclusion criteria were language barrier, contraindication to RA, intolerance to nonsteroidal antiinflammatory drugs, asthma, bleeding diathesis, long-term opioid use, psychiatric history, and pregnancy.

Each patient’s medical history and preoperative daily medication consumption were recorded, and all patients rated the intensity of pain in their hand (operative side) using a 100-mm visual analog scale (VAS). In addition, all patients completed the Pain-Disability Index (PDI) as a preoperative measure of disability due to pain in their hand (operative side). The PDI is a valid self-reported instrument that determines the extent to which pain interferes with normal role functioning in seven daily activities: family/home responsibilities, recreation, social activity, occupation, sexual behavior, self-care, and life-support activity.

Using a computer-generated randomization table, patients were allocated to receive either RA or GA immediately before surgery. Patients allocated to RA were taken to the regional block room for peripheral nerve blockade and subsequently transferred to the operating room (OR), whereas those allocated to GA were taken directly to the OR. Standard monitors were applied to all patients, including noninvasive blood pressure monitor, electrocardiograph, and pulse oximeter, and intravenous access was secured on the nonoperative side for commencement of a 0.9% saline infusion. All patients received intravenous midazolam, 0.03 mg/kg, and ketorolac, 15 mg, before induction of anesthesia.

Patients randomized to RA received a transarterial axillary brachial plexus block performed by a skilled anesthesiologist or directly supervised delegate. On the operative side, the shoulder was abducted, and the elbow was flexed to 90°. The axilla was prepared using an aseptic technique, and the axillary artery was palpated. A subcutaneous injection of 2% lidocaine, 1 ml, provided anesthesia to skin. A 1-in, 23-gauge, noninsulated, long-beveled needle (PrecisionGlide; Becton Dickinson, Franklin Lakes, NJ) was then introduced, and on confirmation of needle tip placement immediately posterior to the axillary artery (by negative aspiration of blood), 1.5% lidocaine, 10 mg/kg, with 1:200,000 epinephrine was injected incrementally. The time at which the anesthesiologist attended the patient, the needle–skin puncture, the time at injection, and the time of onset of surgical anesthesia were all recorded. In addition, the number of needle–skin punctures (i.e., attempts), duration of needle–skin penetration, incidence of transient paresthesiae on RA administration, and any other complications, including pain on injection of the local anesthetic, were noted. Supplementary peripheral nerve blocks at the elbow or wrist were not performed.

Surgical anesthesia at the operative site was determined immediately before incision. Inadequate anesthesia was defined as pain on pinch in the surgical site using Allis forceps. In the event of inadequate anesthesia, a standardized algorithm was followed (standard of practice in our institution): The surgeon first infiltrated the surgical site with 1–2% lidocaine or 0.25–0.5% bupivacaine. Fentanyl, 25 μg, could also be administered every 5 min up to a maximum of 100 μg/h. Patients who had inadequate analgesia despite these measures switched to GA. Inadequate anxiolysis was treated by administration of 10–20 mg propofol every 5 min as required.

The quality of the RA was recorded as follows: (1) adequate: no supplemental analgesic or sedation required for surgery to proceed within a 30-min period from institution of axillary block; (2) inadequate: supplemental analgesic, sedation, or both required for surgery; or (3) failed: GA required for surgery. Patients in the RA group who required GA because of inadequate analgesia, anxiolysis, or both were assessed in the final analysis as part of the RA group (intention-to-treat analysis).

General anesthesia comprised a standardized intravenous regimen including 2–3 mg/kg propofol and 2 μg/kg fentanyl. A laryngeal mask airway or endotracheal tube was used for airway management during surgery. Patients who required tracheal intubation were paralyzed with 0.6 mg/kg rocuronium. Maintenance of GA was provided with a 50:50 mixture of oxygen and nitrous oxide and 2–6% desflurane. Muscle relaxation was antagonized with 50 μg/kg neostigmine and 5–10 μg/kg glycopyrrolate if necessary.

All patients had an upper arm tourniquet applied and inflated to 100 mmHg above their systolic blood pressure (minimum 200 mmHg). Both the tourniquet pressure and the duration of tourniquet inflation were recorded.

During postoperative recovery in the hospital, pain (VAS pain score of ≥ 40 mm or patient request for analgesic) was treated with 25-μg fentanyl increments every 5 min. When oral fluid intake was initiated, patients received one of two oral analgesic preparations as needed: Tylenol #3 (300 mg acetaminophen–30 mg codeine–15 mg caffeine per tablet; McNeil Consumer Healthcare, Guelph, Ontario, Canada) or 325 mg acetaminophen–5 mg oxycodone HCl per tablet if intolerant to codeine.

At the time of discharge from the hospital, patients received a further prescription for Tylenol #3 or 325 mg acetaminophen–5 mg oxycodone HCl and were instructed to take 1–2 tablets every 4 h as required for pain up to a maximum of 12 tablets/day.

Intraoperatively, the anesthesia induction time, total surgical time, total tourniquet time, and total anesthesia time were recorded. On termination of surgery and anesthesia in the OR, fast-track eligibility using the Modified Aldrete score was determined. The Modified Aldrete score rates patient activity, respiration, circulation,
consciousness, and oxygen saturation as a measure of discharge readiness from the PACU to the DSU but has recently been used as a surrogate measure of eligibility to bypass the PACU, i.e., “fast tracking.” At 30-min intervals postoperatively, VAS pain scores and Post-Anesthesia Discharge Scoring System home-readiness scores were collected by an unblinded research assistant.

The Post-Anesthesia Discharge Scoring System is a valid and reliable cumulative index designed to assess eligibility for discharge home after surgery and anesthesia. Durations of stay in the PACU (PACU recovery time) and DSU (DSU recovery time) were also recorded.

At the time of discharge from hospital, patients were given a home diary to complete and return by mail. On postoperative days (PODs) 1, 7, and 14, patients were instructed to document their VAS pain score, daily and cumulative oral analgesic consumption since discharge from the hospital, incidence of nausea or vomiting, incidence of weakness in the operative arm, incidence of paresthesiae (numbness or tingling) in the operative arm, and current VAS satisfaction with anesthetic care. Finally, patients were also instructed to repeat the PDI on POD 14. All patients received telephone calls on days 1, 7, and 14 to remind them to complete and return the diary.

The doses of oral codeine or oxycodone consumed by each patient were converted into equianalgesic doses of oral morphine sulfate to facilitate comparison between both groups. Equianalgesic conversion ratios were used according to the general monograph for opioids in the Canadian Pharmacists Association Compendium of Pharmaceuticals and Specialties as follows: oral oxycodone: oral morphine sulfate = 1:2, and oral codeine:oral morphine sulfate = 3:1.

Statistics

Data were analyzed by intention-to-treat using SPSS version 10.0 software (SPSS Inc., Chicago, IL). Normally distributed continuous data were analyzed using the unpaired Student t test. Nonnormally distributed data were analyzed using the Mann-Whitney U test. Differences in proportions were compared by chi-square test. All repeated variables were corrected using the Bonferroni method. Significance was considered at $P < 0.05$.

Sample Size Estimation

We defined our primary outcome as pain intensity (measured by VAS) on POD 14 after ambulatory hand surgery. Because there were no previous data regarding pain intensity 2 weeks after hand surgery, we calculated a sample size of 100 patients (50 per group) using the Cohen $d$ and a medium effect size correlation (SPSS SamplePower, version 1.0) with a type I error rate of 0.05 and power of 0.80. A sample size of 100 patients also ensured adequate power to detect a difference in pain intensity between the RA and GA groups on POD 1.

This was based on data from a previous randomized trial comparing interscalene brachial plexus block to placebo for adjunctive postoperative analgesia after ambulatory shoulder surgery. We anticipated that mean VAS pain scores on POD 1 after ambulatory hand surgery would be 20 and 40 mm for the RA and GA groups, respectively, with an SD of 30 mm. To detect a 20% difference in VAS pain scores on POD 1 with a type I error rate of 0.01 and a power of 0.80, we calculated that 60 patients (30/group) would be required.

Results

Preoperatively on the day of surgery, we approached 212 patients in the DSU to recruit and obtain consent for the current study. Eighty-five patients did not meet inclusion criteria for the following reasons: refusal to participate, 69 patients; language barrier, 6; weight > 100 kg, 2; medication intolerance/allergy, 2; age < 18 yr, 2; long-term opioid use, 2; psychiatric disease, 1; and participation in another clinical trial, 1. Twenty-seven patients gave consent and were randomized but were subsequently excluded for the following reasons: anesthesiologist favored RA, 11 patients; lost to follow-up, 9; full stomach, 3; surgery canceled, 2; withdrawal of consent, 1; and intraarticular steroid injection during surgery, 1. A total of 100 patients complied with the protocol and completed the study.

Patient characteristics (except weight), medical history, American Society of Anesthesiologists physical status, preoperative VAS and PDI scores, surgeon, and types of hand surgery did not differ between the RA and GA groups (table 1). Procedure types included tendon and nerve repair, fracture fixation and arthrodesis, digital amputation, and hardware removal.

There was no difference in intraoperative tourniquet pressure (RA, 245.0 ± 35.3 mmHg; GA, 245.0 ± 35.3 mmHg; $P = 1.000$) or duration of tourniquet inflation (RA, 44.6 ± 20.3 min; GA, 51.6 ± 22.4 min; $P = 0.103$) between groups. During RA administration, the median amount of needle-skin punctures (i.e., attempts) was 1/patient (range, 1–7). Needle-skin penetration lasted 7.7 ± 5.8 min/patient. Although transient paresthesiae occurred in 33 patients, no patients reported intense pain on injection of local anesthetic suggestive of intraneural injection. Inadequate RA was recorded in 14 patients, of whom all required intraoperative local anesthetic infiltration by the surgeon (mean dose of lidocaine in 5 patients, 77.1 ± 26.9 mg; mean dose of bupivacaine in 9 patients, 35.0 ± 26.0 mg), 11 required intraoperative fentanyl supplementation (mean dose, 59.1 ± 16.9 µg), and 7 required intraoperative propofol (mean dose, 144.3 ± 137.8 mg). Five patients (10%) randomized to RA required conversion to GA because of block failure.
Table 1. Patient Characteristics

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<th>RA Group (n = 50)</th>
<th>GA Group (n = 50)</th>
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<td>Age, yr*</td>
<td>42.5 (16)</td>
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<td>27.5 (0–51)</td>
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<td>Surgical duration, min*</td>
<td>54.4 (23.1)</td>
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<td>Tourniquet time, min*</td>
<td>44.6 (20.3)</td>
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| * Data presented as mean (SD). † Data presented as median (range). ASA = American Society of Anesthesiologists (physical status); GA = general anesthesia; PD = Pain-Disability Index; RA = regional anesthesia; VAS = visual analog scale.

Of the 50 patients randomized to GA, 44 patients were treated with a laryngeal mask airway, whereas 6 required tracheal intubation for airway management.

The anesthesia time (time from which the anesthesiologist attended the patient to time at which patient care was transferred in PACU) was shorter in the GA group (RA, 112.3 ± 27.3 min; GA, 92.6 ± 25.9 min; P < 0.001) primarily because in the RA group this included the time spent instituting RA in the regional block room before entering the OR. The duration of surgical time was similar between groups (RA, 54.4 ± 23.1 min; GA, 62.0 ± 24.4 min; P = 0.111); however, the total (surgical plus anesthesia) time in the OR was significantly shorter in the RA group (RA, 71.3 ± 22.9 min; GA, 90.0 ± 25.7 min; P < 0.001). Upper airway obstruction developed in one patient in the GA group after extubation of the airway, and the patient was admitted to hospital overnight for observation.

After surgery, more RA patients (RA, 49; GA, 27; P < 0.001) were fast-track eligible, and PACU recovery time was shorter in the RA group (RA, 34.5 ± 22.7 min; GA, 73.2 ± 31.0 min; P < 0.001). Although there were no differences in DSU time between groups (RA, 65.9 ± 43 min; GA, 68.7 ± 35.4 min; P = 0.7) if the time spent in PACU and DSU are combined the RA patients spent significantly less time in the hospital before discharge after leaving the OR (RA, 100.4 ± 45.6 min; GA, 142.6 ± 49 min; P < 0.001).

In addition, more RA patients achieved home-readiness criteria at 30 min (RA, 49; GA, 36; P = 0.01) and 90 min (RA, 50; GA, 44; P < 0.05) postoperatively, but there was no statistical difference at 60 min (RA, 49; GA, 43; P = 0.12) or 120 min (RA, 50; GA, 46; P = 0.16).

During in-hospital recovery, the time to first analgesic request was longer in the RA group (RA, 97.6 ± 50.2 min; GA, 29.9 ± 22.8 min; P < 0.001). Fentanyl consumption (RA, 7.0 ± 22.0 μg; GA, 77.5 ± 50.3 μg; P < 0.001), oral morphine equivalent consumption (RA, 7.3 ± 15.2 mg; GA, 22.8 ± 18.1 mg; P < 0.01) (table 2), and VAS pain scores (fig. 1) were lower in the RA group. A greater number of GA patients (GA, 12; RA, 3; P < 0.05) experienced nausea, vomiting, or both requiring antiemetics during recovery in the hospital. Two of the three RA patients who required antiemetics for nausea, vomiting, or both in the hospital had undergone conversion to GA for a failed brachial plexus block.

On PODs 1, 7, and 14, there were no differences in pain (fig. 1) or satisfaction scores or in daily or cumulative oral morphine equivalent consumption (table 2). All patients reported moderate pain on PODs 1 and 7 (fig. 1). The incidence of nausea or vomiting did not differ between groups on PODs 1, 7, and 14. There was no

Table 2. Postoperative Analgesic Consumption and Adverse Effects

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<th>GA Group (n = 50)</th>
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<td>Time to first analgesic request, min*</td>
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<td>29.9 (22.8)</td>
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<td>Intravenous fentanyl in PACU, μg*</td>
<td>7 (22)</td>
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<td>Oral morphine equivalent in PACU and DSU, mg*</td>
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<td>Nausea and vomiting in PACU/DSU, No. of patients</td>
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* Data presented as mean (SD). † Two patients received general anesthesia (GA) for regional block failure.

DSU = day surgery unit; PACU = postanesthesia care unit; POD = postoperative day; RA = regional anesthesia.

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difference in PDI scores on POD 14. Both groups reported equally high satisfaction scores on PODs 1, 7, and 14 regarding the type of anesthetic they received for their hand surgery.

The incidence of postoperative paresthesiae in RA patients at 2 weeks postoperatively was not associated with the number of needle–skin punctures ($P = 0.875$), duration of needle–skin penetration ($P = 0.922$), or occurrence of transient paresthesiae ($P = 0.465$) on RA administration. The incidence of reported paresthesiae was similar in both groups at 2 weeks (GA, 22; RA, 20; $P = 0.44$).

**Discussion**

This is the first prospective randomized controlled study comparing RA against GA for hand surgery. We did not confirm our hypothesis that the improved early pain control with RA would confer analgesic benefits up to 14 days after surgery. In fact, both groups had moderate pain both at 24 h and 7 days after surgery, indicating that patients have significant pain at home after ambulatory hand surgery. The failure to demonstrate a preventive analgesic benefit is probably because central sensitization occurred in both groups after the anesthetic effect had receded, especially in the first few days after surgery, when moderate pain was experienced. This may have been different had we used a long-acting local anesthetic or local anesthetic infusion to prolong pain control into POD 1. However, recent studies indicate that the use of local anesthetics alone to produce preventive analgesia has disappointing results. Although both groups did receive ketorolac before surgery, greater efforts to reduce central sensitization, such as the use of an $N$-methyl-$\alpha$-aspartate receptor antagonist, may have been more successful in reducing pain in the days and weeks after surgery.

Despite our disappointing results with regard to pain control after discharge, we have demonstrated that brachial plexus block provides a significantly better quality of recovery in comparison to GA. Patients who underwent RA benefited from superior postoperative pain control with decreased adverse effects that facilitated fast-track eligibility and hospital discharge after ambulatory hand surgery compared with GA.

In contrast to existing retrospective data supporting improved satisfaction rates in patients who receive RA compared with GA for ambulatory upper extremity surgery, our results suggest equally high satisfaction scores for patients in both groups. The high satisfaction scores observed in the GA group may well reflect the minimal side effect profile of the general anesthetic agents used in the current study. However, patient satisfaction with anesthesia may be influenced by many other factors that occur in the perioperative period.

By decreasing the duration of time the patient spends in the OR and the PACU, we can reduce perioperative costs. The current study demonstrates that RA significantly shortens time in both the OR and the PACU compared with GA. The most likely reason for the shortened total intraoperative time observed in the RA group is that brachial plexus blockade was performed outside the OR in a separate regional block room. Longer anesthesia times were observed in RA patients, but the costs of valuable OR time were spared and efficiency was maximized because the patients had an anesthetized limb and were ready for surgery as soon as they were transferred to the OR. This time efficiency could, at best, lead to the ability to perform more cases per day or at least avoid the cancellation of cases due to delay in the OR. However, the use of a separate block room has cost implications in itself that may outweigh any benefit gained from the reduced OR time.

We demonstrated that with RA, patients spent significantly less time in the hospital and were discharged significantly earlier after surgery than with GA ($P < 0.001$), primarily because of a reduction in PACU time. Patients in the GA group had greater pain, required significantly more analgesics while in the hospital, and experienced greater nausea. However, there was actually no difference between groups in terms of time spent in the DSU, despite the overall reduced time spent in the hospital after surgery in the RA group. Time spent in the DSU is affected by numerous confounding factors, such as dressing the patient and the availability of patient chaperones and transport, and this may have resulted in our inability to demonstrate a reduction in DSU time in the RA group.

The most recent American Society of Anesthesiologists Closed Claims database analysis in 1999 revealed that the use of RA is more frequently associated with claims involving nerve damage compared with GA, but the mechanism of nerve injury has yet to be defined. RA may cause nerve injury by way of direct needle trauma, local anesthetic toxicity, or pressure-induced ischemia. Alternatively, nerve injury may be unrelated to RA and due to patient position, prolonged tourniquet inflation, or surgical technique. Nevertheless, many anesthesiologists do not provide RA for fear of medicolegal action stemming from our inability to demonstrate a reduction in DSU time in the RA group.
from nerve damage.\textsuperscript{24} Despite widely held beliefs that RA causes nerve damage more readily than GA, there have been no randomized trials comparing adverse postoperative neurologic outcome in patients receiving RA \textit{versus} GA for upper extremity surgery. The current study demonstrates that, although the incidence of postoperative paresthesiae is surprisingly high in all patients after ambulatory hand surgery, there is no difference in neurologic symptoms between RA and GA groups up to 2 weeks after surgery. These data tell us nothing about the cause of the neurologic symptoms, but they do tell us that neurologic symptoms are common after hand surgery and that all potential causes of such symptoms should be explored before apportioning blame.\textsuperscript{25}

This study has a number of limitations, including use of an open-label technique; a short-acting local anesthetic agent; and a single-shot, single-endpoint brachial plexus block technique.

Although all data in the hospital were collected by an unblinded research assistant, it would have been extremely difficult to blind a research assistant to a patient recovering from RA compared with GA. However, the validated scoring systems used for data collection in the hospital (such as Aldrete and Post-Anesthesia Discharge Scoring System) may reduce the potential for introduction of bias. All data recorded at home were by patient self-report in a diary, without contact with any member of the research team. Telephone calls were made to remind patients to complete the diary, but no assistance was given with completion.

Although single-endpoint axillary block techniques are associated with a lower success rate then multiple-endpoint techniques,\textsuperscript{26} we wanted to use a technique that is commonly used and therefore able to be generalized to a wider population. Certainly the block failure rate observed in this study could be improved with the use of a multiple-endpoint technique. However, transarterial axillary brachial plexus block has an easily recognizable endpoint and is easy to teach and learn. For this reason, it is the preferred axillary technique taught at our institution for ambulatory hand surgery given the record of success and safety with which it is associated.\textsuperscript{27}

Lidocaine, 1.5\% (10 mg/kg), is our local anesthetic agent of choice for axillary brachial plexus block in patients undergoing ambulatory hand surgery because of its rapid onset, but it is limited by a short duration of action. The use of a longer-acting agent may have extended duration of analgesia into the first POD.

\section*{Future Directions}

Efforts should be directed at reducing the pain experienced by patients in the early postoperative period at home after ambulatory hand surgery. Improved patient education could provide a simple but beneficial intervention. Prolongation of analgesia with multimodal techniques\textsuperscript{28} such as the use of controlled-release opioids,\textsuperscript{29} nonsteroidal antiinflammatory agents, or both could provide benefit. Recently evaluated techniques such as patient-controlled RA that enable continuous axillary brachial plexus blockade at home\textsuperscript{30} may help to reduce the moderate pain that patients experience during the first week after ambulatory hand surgery.

\section*{Summary}

In conclusion, RA when compared with GA did not result in better pain control at home up to 14 days following ambulatory hand surgery. However RA did provide improved early pain control with less adverse effects and faster hospital discharge.

\section*{References}


A Simple Technique to Properly Position a Swan Ganz Catheter in Cardiac Surgical Patients with Situs Inversus

To the Editor:

Situs inversus is characterized by dextrocardia and a mirror image of the situs solitus, which is the normal arrangement of viscera (1). Although cardiac surgery has been reported in these patients (2), no information is available on how to successfully position a Swan Ganz catheter without fluoroscopy because of important anatomical changes encountered.

A 39-year-old female patient (height, 169 cm; weight, 56 kg) with complete situs inversus developed isolated symptomatic (grade 3) aortic valve regurgitation and was scheduled for replacement of the aortic valve. A heparin-coated 7.5F thermodilution 4-lumen catheter was introduced via the left internal jugular vein (Fig. 1), superior vena cava until the tip reached 30 cm from the catheter entry. The distal balloon was inflated, and the tip directed to the right ventricle. This was obtained at 35 cm and confirmed by the pressure waveform. The catheter was pushed right into the right ventricle. This was obtained at 35 cm and confirmed by a chest radiograph (Fig. 1).

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A Novel Approach to Infraclavicular Brachial Plexus Block: The Ultrasound Experience

To the Editor:

We read with interest the recent article by Klaastad et al. (1) which describes a novel approach to infraclavicular block where the needle is inserted immediately medial to the coracoid process and directed posteriorly with a 15 degree angle to the coronal plane. We have also modified our approach in a similar manner for coracoid infraclavicular block when we are using an ultrasound-guided technique. In our experience, inserting the needle adjacent (2 cm medial) to the coracoid process at the inferior border of the clavicle and advancing posteriorly with a 15 degree angle to the coronal plane consistently localizes the cords, which are often situated superior and posterior to the axillary artery at a depth of 4–6 cm. The trajectory of this approach appears to avoid puncture of the axillary vessels while the cords are encountered 2–3 cm cephalad to the pleural cavity (Fig. 1). This is in contrast to the traditional “blind” coracoid approach that would appear to invite vascular or pleural puncture in order to reach the cords of the brachial plexus in a proportion of cases. The use of ultrasound in combination with nerve stimulation with this approach has enabled us to improve our block success and decrease morbidity.

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In Response:

Our group appreciates the interest of Brull et al. in our article (1). Their technique aided by ultrasound is indeed similar to ours. Using
Needle placement and injection posterior to the axillary artery may predict successful infraclavicular brachial plexus block: a report of three cases

[La position de l’aiguille et l’injection postérieure à l’artère axillaire peuvent prédire la réussite d’un bloc sous-claviculaire du plexus brachial : présentation de trois cas]


Purpose: The combined use of ultrasound and nerve stimulation for localization of the brachial plexus during infraclavicular block has not been evaluated. We describe three cases of infraclavicular block where we used ultrasound to place the needle and catheter, observe type of muscle twitch obtained and local anesthetic spread after injection.

Clinical features: Injection of local anesthetic after obtaining proximal muscle stimulation was associated with local anesthetic spread between the axillary artery and pectoral muscle. This resulted in block failure (case 1).

In case 2, proximal stimulation was associated with anterior spread after a test injection. The needle and subsequently the catheter were repositioned posterior to the axillary artery and distal muscle stimulation obtained. Injection through the catheter resulted in local anesthetic spread posterior to the artery and successful block.

In case 3, no distal twitch could be obtained but in light of previous experience the needle and then the catheter were placed posterior to the axillary artery. Posterior local anesthetic spread was observed and successful block ensued despite absence of any muscle stimulation.

Conclusion: Ultrasound guidance during infraclavicular brachial plexus block enables direct visualization of needle/catheter tip location and confirmation of appropriate local anesthetic spread. Our early experience suggests that spread of injectate posterior to the second part of the axillary artery is associated with successful block.

Objectif: La combinaison d’ultrasounds et de neurostimulation pour localiser le plexus brachial lors d’un bloc sous-claviculaire n’a pas été évaluée. Nous décrivons trois cas de bloc sous-claviculaire où les ultrasons ont été utilisés pour placer l’aiguille et le cathéter, observer le type de contraction musculaire obtenue et la diffusion de l’anesthésique local après l’injection.

Éléments cliniques : Après l’obtention d’une stimulation proximale, l’injection d’anesthésique local a été associée à la diffusion de l’anesthésique entre l’artère axillaire et le muscle pectoral et elle a entraîné un échec du bloc (Cas 1).

Dans le cas 2, la stimulation proximale a été associée à une diffusion antérieure après une injection d’essai. L’aiguille et, par la suite, le cathéter ont été replacés en position postérieure à l’artère axillaire et une stimulation du muscle distal a été obtenue. L’injection au travers du cathéter a amené la diffusion de l’anesthésique local derrière l’artère et la réussite du bloc.

Dans le cas 3, aucune contraction distale n’a pu être obtenue, mais fort de l’expérience précédente, l’aiguille et, ensuite, le cathéter ont été placés postérieurement à l’artère axillaire. La diffusion postérieure de l’anesthésique local a été observée et suivie d’un bloc réussi malgré l’absence de toute stimulation musculaire.

HE coracoid infraclavicular block is a useful technique that allows block of all three cords of the brachial plexus with less risk of pneumothorax than with a supraclavicular approach.

However the infraclavicular approach can be a difficult technique to master using nerve stimulation techniques alone. Proximal muscle stimulation (biceps, pectoralis or triceps) is often encountered initially but injection of local anesthetic at this end-point is associated with success rates as low as 44%. Distal muscle stimulation in the forearm or hand is often more difficult to achieve but is required to optimize block success. Repeated attempts to seek this end-point may be associated with risk of vascular puncture or pneumothorax and patient discomfort.

The use of ultrasound has been demonstrated in a number of studies to facilitate correct needle placement and produce successful infraclavicular block. However no information is currently available on which needle position, as demonstrated by ultrasound, correlates with the greatest likelihood of finding a distal twitch with nerve stimulation or of subsequent successful block.

We describe three cases of ultrasound guided infraclavicular block that may help to further our knowledge of what occurs during successful or unsuccessful coracoid infraclavicular brachial plexus blocks.

In all three cases, we used standard monitoring, secured and iv access and started an infusion of saline 0.9%. Intravenous midazolam 2 mg and fentanyl 50 µg were administered for sedation.

The block was performed with the patient lying supine and the head turned away from the limb to be blocked. The arm was placed in a neutral position (adducted). After sterile preparation the coracoid process was identified by palpation and a point 2 cm caudal and 2 cm medial to the coracoid process was marked, as previously described by Wilson. Lidocaine 1% 1 to 2 mL was infiltrated at a point approximately 1 cm superior to this point.

Using a sterile technique, a Philips ATL HDI 5000 SonoCT unit (Philips Medical Systems ATL Ultrasound, Bothell, WA, USA; 4–7 MHz probe) was used to scan the infraclavicular area in the parasagittal plane.

The needle was advanced in the long axis of the probe (Figure 1) and in the same plane as the ultrasound beam. A 17-gauge (G) insulated Tuohy needle (Arrow International, Reading, PA, USA) was inserted under direct vision and the needle tip advanced initially towards the superior aspect and then posterior to the axillary artery and distal muscle stimulation sought using an initial current of 1.5 mA. Following insertion of the catheter, 40 mL lidocaine 1.5% with 1:200,000 epinephrine were administered in 5-mL increments via the catheter (with repeated aspiration).

**Case report 1**

A 39-yr-old male presented for hand surgery and gave informed consent for coracoid infraclavicular brachial plexus block.

Nerve stimulation with a current of 1.5 mA was performed but no distal muscle stimulation could be obtained by positioning the needle tip at the superior, posterior and inferior aspects of the artery. Insertion of the needle tip inferior to the axillary artery and between the vein and artery produced pectoral muscle
stimulation at 0.5 mA. A stimulating catheter was inserted and pectoral muscle stimulation was maintained (Figure 1i). The catheter tip and local anesthetic spread were clearly visualized between the vascular structures and pectoralis muscle on the ultrasound image (Figure 1ii). Complete block failure occurred in this case and general anesthesia was induced for surgery. The infraclavicular catheter was removed in the postanesthesia care unit.

**Case report 2**

A 40-yr-old female presented for hand surgery and gave informed consent for coracoid infraclavicular brachial plexus block.

Insertion of the stimulating needle at the superior aspect of the axillary artery produced biceps muscle contraction at a current of 1.5 mA. In order to determine if injectate spread would occur around the axillary artery, a test dose of 5 mL was injected. Spread of injectate between pectoralis muscle and axillary artery was observed (Figure 2i). The needle was then advanced to the posterior aspect of the axillary artery (between artery and subscapularis muscle). Distal muscle stimulation in the radial nerve distribution was obtained at this point using a current < 0.5 mA. A stimulating catheter was inserted and distal stimulation was maintained during insertion (Figure 2ii). Injected local anesthetic could be clearly seen spreading posterior to the second part of the axillary artery (Figure 2iii). Successful motor and sensory block of the upper limb occurred within 30 min of injection.

The catheter was also used to provide postoperative analgesia with a continuous brachial plexus infusion of 5 mL·hr⁻¹ 0.2% ropivacaine.

**Case report 3**

A 46-yr-old female presented for hand surgery and consented to infraclavicular brachial plexus block. After insertion of the stimulating needle, musculocutaneous stimulation was obtained at the superior aspect of the artery but no distal muscle stimulation could be obtained at either the superior, inferior or posterior aspects of the second part of the axillary artery using currents up to 1.5 mA. Based on previous experience and anatomical knowledge of the position of the brachial plexus in relation to the axillary artery at this point, the needle tip (and subsequently the catheter) were positioned posterior to the axillary artery. The injected local anesthetic could be clearly seen spreading posterior to the second part of the axillary artery (similar pattern to Figure 2iii). Successful motor and sensory block of the upper limb occurred within 15 min of injection. The catheter was also used to provide postoperative analgesia with a continuous brachial plexus infusion of 5 mL·hr⁻¹ 0.2% ropivacaine.

**Discussion**

Distal muscle stimulation is required for infraclavicular block using existing methods of nerve localization in order to obtain acceptable success rates.¹² Proximal
Muscle stimulation (biceps, triceps or pectoralis) is much easier to obtain but associated with a poor rate of successful block.\textsuperscript{1,2} In the current report, proximal muscle twitch was initially obtained in two of the three cases. In our first case, only pectoralis twitch was obtained and injection through the catheter at this end-point led to anterior spread of local anesthetic between the axillary artery and pectoralis muscle and block failure. In cases 2 and 3, successful block occurred after visualization of local anesthetic spread posterior to the axillary artery. The anatomy of the brachial plexus is variable at the infraclavicular level. Using ultrasound to visualize the plexus as it passes from its origin in the neck to the axilla, it appears to move from a posterior position in relation to the axillary artery at the infraclavicular level, to the classical anatomical position of the cords (lateral cord superior, posterior cord posterior and medial cord postero-inferior) to the axillary artery (unpublished data).

The musculocutaneous nerve often leaves the lateral cord at or above the infraclavicular level and may explain why injection after biceps stimulation is often associated with inadequate block.\textsuperscript{5} In two of our cases, proximal stimulation was associated with anterior spread of local anesthetic, which may fail to reach the brachial plexus leading to block failure. In several of our ultrasound images, spread posterior to the axillary artery appeared to be prevented by a tissue barrier that lay between the needle tip and artery (Figures 1ii and 2i).

In two of the three cases described, we failed to identify distal muscle stimulation despite manipulation of the needle tip to all aspects of the axillary artery. This may be explained in part by the electrical qualities of the arrow 17-G insulated Tuohy needle. However, this also corroborates documented difficulty in obtaining distal muscle stimulation observed by ourselves and by other authors.\textsuperscript{2} Repeated blind attempts to seek distal muscle stimulation can be associated with increased morbidity.
such as vascular puncture and patient discomfort. Pleural puncture is also possible at the infraclavicular level and the distance from skin to pleura using the coracoid technique may be as low as 7.5 cm. The use of ultrasound guidance allows identification and avoidance of vascular and pleural structures as the needle tip is guided in ‘real-time’ to the point of injection.

The findings of the present case series need to be confirmed with experience in a larger number of cases and by a randomized study to further determine the type of stimulation associated with needle position and spread of local anesthetic during infraclavicular block. In addition, our hypothesis that successful block is associated with spread of local anesthetic posterior to the axillary artery needs to be confirmed in a larger series of patients.

In conclusion, ultrasound guidance during coracoid infraclavicular brachial plexus block may facilitate block success by allowing visualization of the needle/catheter tip location in addition to observation of local anesthetic spread on injection. At the level of the second part of the axillary artery, posterior spread of local anesthetic may increase the possibility of successful block because of the anatomical location of the brachial plexus at this level.

References
Letters to the Editor

Ultrasound Guidance for Brachial Plexus Localization and Catheter Insertion After Complete Forearm Amputation

To the Editor:

Brachial plexus block is used commonly for intraoperative and postoperative anesthesia and analgesia for upper-limb surgery. Patients may benefit from superior analgesia and reduced requirements for systemic opioids. Beyond that, the sympatholytic effect of peripheral-nerve block is thought to improve vascular flow and perfusion. This effect may be desirable in patients with vascular anastomoses; for example, after reimplantation of amputated limbs.

We encountered a case in which the use of conventional endpoints (distal muscle twitches, transarterial approach) for a brachial-plexus block was not possible, and successful placement of a brachial-plexus catheter was only feasible through the use of ultrasound.

A patient with complete amputation of the forearm underwent a reattachment procedure. At the end of the procedure, the surgical team and the anesthesiologists agreed that continuous brachial-plexus block would greatly benefit the patient with regard to postoperative analgesia and the potential for improved vascular perfusion, but the procedure was considered to carry significant risks. Potential needle injury to the subclavian or axillary artery during blind insertion was a relevant risk because the patient was coagulopathic after major blood loss. Nerve localization and eliciting a distal motor response with a peripheral-nerve stimulator was impossible because of the forearm amputation. Under ultrasound guidance, placement of an infraclavicular brachial-plexus block catheter posterior to the artery was possible by use of the modified coracoid approach, without any complications. The catheter was successfully used for surgical analgesia when re-exploration of the anastomosis became necessary on the same day and provided good pain relief for the first 8 postoperative days, when it was removed. As perfusion of the arm had deteriorated in the preceding days, a new catheter was inserted as per surgical request. This catheter was repositioned in the axilla for fear of infection developing at the original skin site. Because no palpable axillary arterial pulsation occurred, placement was performed by use of a peripheral-nerve stimulator-guided, ultrasound-assisted technique. Ultrasound imaging allowed for easy visualization of the artery. Five days later, the patient experienced pain, and the catheter was thought to be dislodged. It was safely replaced by an infraclavicular catheter, again under ultrasound guidance and without complications.

Another 2 days later (postoperative day 15), the patient again experienced pain, and local anesthetic leakage, presumed to come from the catheter-insertion site, was noted. After removal of the dressing, no evidence for leakage from this site was seen. Rather than replacement of the catheter, 20 mL of lidocaine was injected under direct ultrasound observation to identify the position of the catheter tip. It was visualized immediately posterior to axillary artery. The injection also demonstrated good spread of local anesthetic posterior to the artery in a pattern previously observed to provide effective anesthesia and analgesia. At the same time, a leak at the distal connector-site end of the catheter was identified. The connector was changed and local anesthetic infusion resumed. The catheter remained in situ for a further 4 days. Continuous brachial-plexus block was finally discontinued on postoperative day 19 and the catheter removed after successful titration of oral analgesic medication.

Despite maximum medical treatment, the perfusion of the distal limb deteriorated further, and signs of infection developed. Unfortunately, on the 12th postoperative day, the forearm had to be amputated at the site of injury under general anesthesia.

In conclusion, ultrasound-guided, brachial-plexus catheter insertion and evaluation repeatedly facilitated accurate continuous deposition of local anesthetic and allowed for an avoidance of complications.

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Lateral Popliteal Sciatic-Nerve Block Made Easy

To the Editor:

The association of sciatic-nerve and saphenous-nerve blocks has proved extremely efficacious in providing sur-
Case report

Ultrasound as the only nerve localization technique for peripheral nerve block

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Abstract Ultrasound facilitates the performance of peripheral nerve blocks and may increase block quality parameters. In this report, we show that ultrasonographic guidance makes peripheral nerve blocks possible in patients in whom the traditional methods of nerve localization are limited. Four cases are described in which conventional end points for successful blocks would have been impossible to use, whereas ultrasound guidance was successful and safe. The latter method increases applicability in a larger group of patients.

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1. Introduction

Direct ultrasonographic visualization in peripheral regional anesthesia may be an improvement over present techniques. Direct visualization of nerves with local anesthetic spread increases block success rate and may prevent complications [1]. With ultrasound, it is possible to perform peripheral nerve blocks in patients in whom other nerve localization techniques (nerve stimulation and parasthesia) are not useful [2,3].

We present four cases of ultrasound-guided peripheral nerve blocks in which a motor response to nerve stimulation was difficult or even impossible to obtain.

2. Case reports

2.1. Case 1

A 42-year-old man was scheduled for secondary wound closure after osteosarcoma resection of the femur, femoropopliteal bypass grafting, and fasciotomy. As a result of this surgery, the sciatic nerve was damaged at the level of the distal femur. The patient was unable to move his foot and he had allodynia with hyperesthesia in the sciatic nerve distribution. Therefore, we expected that motor response to electrical nerve stimulation would be difficult or impossible to obtain. A subgluteal sciatic nerve block with ultrasonographic guidance was planned.

With the patient placed in Sim’s position, the sciatic nerve in the posterior thigh near the gluteal crease was visualized with a 5- to 10-MHz 38-mm linear ultrasound...
transducer (Sonosite Titan, Bothell, WA) and then a 40-mm Stimuplex D needle with 30° bevel (B. Braun, Melsungen, Germany) was positioned near the nerve. The electrical nerve stimulator (HNS 11, B. Braun) was activated and the current was increased progressively. Nerve stimulation with 2.2 mA, one ms, one Hz, resulted in painful sensations in the distribution of the distal sciatic nerve, but no motor response was obtained. During the injection of 20 mL of ropivacaine 0.75%, circumferential spread of local anesthetic around the nerve was observed. Twenty minutes later the neuropathic pain disappeared.

During surgery, sedation by continuous propofol infusion at a rate of 100 mg/h was given at the request of the patient. Both surgery and postoperative course were uneventful. The patient had good pain relief for 6 hours after the injection.

2.2. Case 2

A 6-year-old, 25-kg boy who had hereditary motor and sensory neuropathy (HMSN) type 1, which was diagnosed by sural nerve biopsy, was scheduled for right clubfoot repair. Electromyographic testing had shown demyelinating polyneuropathy of the legs with symptoms of muscle weakness and of normal sensation. Six months earlier, the child underwent surgery on the left foot. Postoperative pain was controlled by a continuous morphine infusion but resulted in urinary retention and bladder catheterization. Therefore, the parents asked for an alternative method of postoperative pain relief. We decided to perform an ultrasound-guided distal sciatic nerve block in the popliteal fossa.

After oral premedication with 7.5 mg midazolam, intravenous (IV) access was established and general anesthesia was induced with propofol 75 mg and fentanyl 25 µg IV. Endotracheal intubation was performed without muscle relaxants, and anesthesia was maintained with sevoflurane (end-tidal concentration, 1.7%) in oxygen and air (40%/60%). Thereafter, the patient was turned to the Sim’s position. For the ultrasound-guided popliteal block, the same equipment as described in case 1 was used, and a 40-mm Stimuplex needle was positioned at the proximity of the sciatic nerve, which was identified as a single, round, hyperechoic structure. When the needle position was judged optimal, the neurostimulator was activated and the current was increased progressively. By a stimulation duration of 0.3 ms and a current of 1.5 mA, slight plantar flexion was seen. Ten milliliters of 0.75% ropivacaine was injected while the spread of local anesthetic around the sciatic nerve was monitored (Fig. 1).

Surgery proceeded uneventfully. On postoperative examination, a dense sensory block in the sciatic nerve distribution was present. No analgesics were needed, and the postoperative course was unremarkable. The patient was discharged to home 12 hours after surgery and experienced pain only for 36 hours after the injection of local anesthetic. The pain was then controlled with paracetamol 500 mg and diclofenac 25 mg rectally three times daily.

One week after the operation, neurologic examination showed that the function of the foot was unchanged.

Fig. 1  Ultrasonographic image showing spread of local anesthetic (LA; arrows) around the distal sciatic nerve (SN) in the popliteal fossa.
2.3. Case 3

A 51-year-old man was scheduled for repeat resection of an arteriovenous malformation of the femur. Twelve years earlier, extensive surgery had been performed in which skin, quadriceps muscle, and patella had been removed, followed by arthrodesis of the knee.

The surgery was performed during spinal anesthesia with 60 mg plain lidocaine. Two hours after surgery, the patient complained of severe pain in his thigh, with a
Visual Analog Scale (VAS) pain score of 10. Although he was given morphine 20 and diclofenac 75 mg IV, the pain score decreased only to 6. We decided to perform an ultrasound-guided femoral nerve block because it was impossible to elicit quadriceps muscle contractions on electrical nerve stimulation. For imaging we used the same equipment as described in case 1. With ultrasound guidance, we inserted the 40-mm needle at the inguinal crease and placed it in proximity to the femoral nerve. The spread of local anesthetic (15 mL of ropivacaine 0.75%) around the nerve was followed. Fifteen minutes after injection, the VAS score decreased to 1 and lasted for 10 hours.

2.4. Case 4

A 37-year-old man presented for ambulatory hand surgery during infraclavicular block. A nerve stimulator–guided technique was chosen via a coracoid approach. After stimulation of the brachioradialis muscle at 0.7 mA was obtained, 15 mL of 2% lidocaine with 1:200000 epinephrine and 15 mL of bupivacaine 0.5% with 1:200000 epinephrine were injected. After 15 minutes, only a full block of the musculocutaneous nerve and partial block of the ulnar nerve were evident. Both median and radial nerves still maintained normal function. The decision was made to supplement the infraclavicular block using ultrasound guidance. Initial scan of the second part of the axillary artery showed that the initial bolus of local anesthetic had spread predominantly anterior to the artery, with little spread either superior or posterior to the artery (Fig. 2). Using a 4- to 7-MHz ultrasound probe (Philips HDL500, Philips, Bothell, WA), we guided a 22-gauge, 80-mm needle to the posterior aspect of the axillary artery and, after negative aspiration, an additional 10 mL of 2% lidocaine with 1:200000 epinephrine was injected. The local anesthetic spread posterior to the second part of the axillary artery (Fig. 3). After 15 minutes, complete block of the radial, median, and ulnar nerves was confirmed and surgery proceeded without further anesthetic requirement.

3. Discussion

These cases show the successful use of ultrasound in the performance of peripheral nerve blocks, for which other nerve localizing techniques were not applicable.

Nerve stimulation requires intact nerve fibers and muscles. Muscle fibers can be denervated by damage to motor nerves (as in cases 1 and 2), or by damage to the muscle, as in case 3. Local anesthetic action and neuropathy can diminish the excitability of a nerve. In neuropathy, conduction failure may occur if the reduction in nerve impulse transmission worsens because of demyelination, axonal loss, or both. This action alters the motor response on electrical nerve stimulation. In the first patient, axonal loss resulted in conduction failure over the sciatic nerve in the popliteal fossa, and no motor response was obtained with nerve stimulation.

The second patient had HMSN type 1, which is an inherited demyelinating neuropathy with slowing of the nerve conduction velocity [4]. The HMSN variants show significant variations in clinical penetration and conduction failure. Demyelination requires higher nerve stimulation currents to obtain muscular responses, as is also seen in patients with diabetes mellitus [5]. The final stimulus current intensity, so as to predict a successful block for the different neuropathies, remains unknown. Use of higher current (>1 mA) and a longer stimulation duration (>0.3 ms) is recommended in these situations but does not guarantee a successful block [6]. In both patients, it was necessary to adapt our nerve stimulator settings to obtain some nerve impulse transmission after having localized the nerve by ultrasound.

Incorrect use of the nerve stimulator in case 4 caused a block failure. A musculocutaneous response on electrical nerve stimulation is associated with low-quality coracoid block [7]. A multiple injection technique would have been a better choice [8]. Moreover, the ideal end point for the stimulating current should have been less than 0.5 mA. Further rescue of this block under normal circumstances could have been hazardous and difficult because of the partial block that already existed. Nerve or other injury could have occurred and use of the nerve stimulator would have been extremely unreliable in this case.

In patients with underlying mechanical, ischemic, or metabolic neurologic derangements, needle-nerve contact should be prevented. These patients are at increased risk of progressive neural injury because of possible needle-induced trauma, local anesthetic toxicity, or neural ischemia. It is hypothesized that axons compressed or injured at one site may be particularly susceptible to damage at a more distal location, which may occur with nerve blocks [9]. Hence, the performance of regional anesthesia in cases 1 and 2 is controversial because of the potential risk of progressive nerve injury.

Ultrasound guidance makes successful peripheral nerve blocks possible in patients in whom the traditional methods of nerve localization are limited. In cases 1 and 2, the sciatic nerve was easily visualized and blocked in the infragluteal region, as described by Chan et al [10]. The femoral nerve was visualized and blocked in case 3. Ultrasonographic guidance permits accurate deposition of the local anesthetic around the three cords in infraclavicular block [11]. This procedure was followed in case 4.

In children, it is possible to obtain more high-quality ultrasound images. Their higher total body water content than adults and a more superficial course of the nerves makes visualization of nerves easier in children [12].

Ultrasoundography also has a high potential for follow-up examinations of peripheral nerves in relation to previous nerve damage [13]. In patients with hereditary motor and sensory neuropathies, larger nerves and fascicular diameters are shown [14,15]. We did not perform this examination.
Patients with underlying neurologic diseases, who are at increased risk of progressive neural injury, may undergo peripheral nerve blocks more safely with ultrasound. Ultrasoundography facilitates performance of successful peripheral nerve blocks and renders these pain-relieving techniques available for a larger group of patients.

References

Compared with dual nerve stimulation, ultrasound guidance shortens the time for infraclavicular block performance

L’échoguidage réduit le temps jusqu’à l’efficacité d’un bloc infraclaviculaire par rapport à la stimulation nerveuse double

Richard Brull, MD · Mario Lupu, MD · Anahi Perlas, MD · Vincent W. S. Chan, MD · Colin J. L. McCartney, MB

Abstract

Purpose  The success rate for infraclavicular brachial plexus block using nerve stimulation reportedly ranges from 60 to 80%. Ultrasound guidance may be associated with greater success. This study compared ultrasound guided infraclavicular block with a dual motor endpoint nerve stimulation technique.

Methods  One hundred three hand surgery patients were randomized to receive either ultrasound-guided (ultrasound group) or dual motor endpoint nerve stimulation (stimulation group) infraclavicular block using 2% lidocaine 15 mL and 0.5% bupivacaine 15 mL with epinephrine. Block success was defined as loss of sensation to pinprick in each of the radial, ulnar, median, and musculocutaneous nerve distributions when measured 20 min after block performance. Block performance time, readiness for surgery (no supplemental block, skin infiltration, or general anesthesia), and complications were also assessed.

Results  Patient characteristics were similar between groups. Success rate was 92% in the ultrasound group and 80% in the stimulation group (P = 0.18). Block performance time was shorter in the ultrasound group (median 5 min) compared with the stimulation group (median 10.5 min) (P < 0.001). Paresthesiae were more frequent in the stimulation group (45%) than in the ultrasound group (6%) (P < 0.001). After final injection, more patients were ready for surgery in the ultrasound group (85%) than in the stimulation group (65%) (P = 0.04). At 1 week postoperatively, complications were minor and transient and did not differ between groups.

Conclusion  There was no statistically significant difference in the success rate between ultrasound guidance and dual motor endpoint stimulation for infraclavicular block. However, ultrasound guidance shortens performance time and improves readiness for surgery compared with dual motor endpoint stimulation (Clinical Trial Registration Number: NCT00326261).

Résumé

Objectif  Selon la littérature, le taux de réussite d’un bloc infraclaviculaire du plexus brachial réalisé par stimulation nerveuse se situe entre 60 % et 80 %. L’échoguidage pourrait être associé à un taux de réussite plus élevé. Cette étude a comparé un bloc infraclaviculaire réalisé par échoguidage à une technique de double stimulation nerveuse des extrémités motrices.

Méthode  Cent-trois patients devant subir une chirurgie de la main ont été randomisés à recevoir un bloc infraclaviculaire réalisé soit par échoguidage (groupe échoguidage) ou par double stimulation nerveuse des extrémités motrices (groupe stimulation) à l’aide de 15 mL de lidocaïne 2 % et de 15 mL de bupivacaine 0,5 % avec épinéphrine. La réussite du bloc a été définie en tant que la
Infraclavicular brachial plexus blockade provides good to excellent anesthesia for surgery of the elbow, forearm, wrist, or hand. While various nerve stimulator-guided approaches to infraclavicular block have been described in the literature, such that the elicitation of motor twitches corresponding to at least two cords (i.e., dual motor endpoint) is the most reliable goal for traditional nerve stimulator-guided infraclavicular block. Early reports suggest that ultrasound may be associated with faster onset, greater success, and fewer adverse effects compared with some traditional stimulation-guided approaches for infraclavicular block. However, the most recent evidence suggests that, in expert hands, success rates and onset times for ultrasound-guided and single motor endpoint stimulation-guided infraclavicular block are equivalent. The dual motor endpoint technique has not been compared with an ultrasound-guided technique for infraclavicular block in a randomized fashion. The purpose of this study was to determine if ultrasound-guided infraclavicular block is associated with a greater success rate compared with the dual motor endpoint stimulation technique.

Methods

After obtaining institutional research ethics board approval of the study protocol and written informed consent from all subjects, 106 adult patients, who were American Society of Anesthesiology physical status I–III and scheduled for elective elbow, forearm, wrist, or hand surgery, were studied prospectively. The patients of all four hand surgeons at Toronto Western Hospital were eligible for participation in the present study. Exclusion criteria included age <18 or >70 yr, language barrier, contraindication(s) to regional anesthesia, weight >100 kg, pre-existing neurological deficit in the distribution to be anesthetized, local infection, coagulopathy, chest or shoulder deformities, severe respiratory disease, or clavicle fracture.

Using a computer-generated randomization table, patients were allocated to receive an infraclavicular block using either ultrasound guidance (ultrasound group, n = 53) or stimulation guidance (stimulation group, n = 53). Non-invasive blood pressure, electrocardiogram, and pulse oximetry were applied, and intravenous access was secured on the non-operative side for infusion of a 0.9% saline solution. All patients received midazolam 2–4 mg iv as needed preoperatively for sedation and anxiolysis.

The patient and the research fellow evaluating the infraclavicular block were blinded to group allocation. To ensure the patients were unaware of group allocation, a linear 7–13 MHz Philips/ATL HDI 5000 Ultrasound or a 5–12 MHz Philips HD11 Ultrasound (Philips Medical Systems, Bothell, WA, USA) and a nerve stimulator (Stimuplex®, B. Braun Medical, Bethlehem, PA, USA) were applied to each patient’s skin regardless of group. For the ultrasound group, the nerve stimulator was not grounded, and although an audible signal was present, the nerve stimulator did not function during the block procedure. For the stimulation group, a “sham” ultrasound probe was placed adjacent to the needle insertion point, and the ultrasound screen was placed in a stand-by position facing away from the patient so that the ultrasound machine did not display any anatomical structures of practical use to the anesthesiologist. All patients were positioned supine with the operative-side elbow flexed to 90° and the palm of the hand lying comfortably across the abdomen. All infraclavicular blocks were performed in a nerve block procedure room by one of four experienced regional anesthesiologists. Prior to needle puncture, the skin site was sterilized with a 2% solution of chlorhexidine in 70% isopropyl alcohol.
alcohol and infiltrated with 1% lidocaine 1 mL. A standardized local anesthetic admixture containing 2% lidocaine 15 mL and 0.5% bupivacaine 15 mL with epinephrine 1:200000 (total volume, 30 mL) was used as the injectate in both study groups.

Ultrasound group

The ultrasound probe was positioned medially to the coracoid process and caudally to the clavicle to allow visualization of the axillary artery in the parasagittal plane. Slight rotational movements of the probe were made until a short-axis view of the cords of the brachial plexus was obtained and identified as round hypoechoic nodules located around the second part of the axillary artery. A sterile 22G 50–80 mm insulated needle (Stimuplex®, B. Braun Medical, Bethlehem, PA, USA) was advanced using an in-plane needle approach under ultrasound guidance. In one needle pass, the needle tip was positioned under direct vision adjacent to the lateral cord (9 o’clock position relative to the second part of the axillary artery). In another needle pass, the needle tip was positioned adjacent to the posterior cord (6 o’clock position relative to the second part of the axillary artery). At each of these two positions, 15 mL of the local anesthetic solution were injected incrementally to yield a total volume of 30 mL.

Stimulation group

A sterile 22G 50 mm insulated needle (Stimuplex®, B. Braun Medical, Bethlehem, PA, USA) connected to a grounded nerve stimulator was inserted medially to the tip of the coracoid process and angled 15° to the coronal plane. Two of the following three motor endpoints were sought:

1) lateral cord stimulation (elbow flexion, finger flexion, or thumb opposition);
2) posterior cord stimulation (wrist extension);
3) medial cord stimulation (finger flexion, thumb or wrist adduction).

In order to elicit the motor responses, the needle was redirected 0.5–1 cm superiorly or inferiorly (while maintaining posterior–inferior needle angulation) as needed. At a minimum threshold current of 0.3–0.5 mA for each endpoint, 15 mL of the local anesthetic solution were injected incrementally at each position for a total of 30 mL. If two motor responses were not elicited within 20 min of needle insertion, the procedure was abandoned in favour of a different approach to brachial plexus blockade, and the patient was excluded from data analyses.

All patients were interviewed by telephone at 24 hr and 7 days postoperatively. The occurrences of any adverse events or potential block-related complications were recorded, including paresthesiae, motor deficits, pain, and bruising.

Block evaluation

After injection of local anesthetic, sensory loss and motor blockade were evaluated every 5 min for 30 min. Data collection was performed by an independent observer (research fellow) who was blinded to the group assignment. The extent of sensory loss was tested in the median, radial, ulnar, and musculocutaneous nerve distributions and was evaluated using a 3-point score: 2 = normal sensation, 1 = loss of sensation to pinprick (i.e., analgesia), or 0 = loss of sensation to light touch (i.e., anesthesia). Also recorded were the block performance time (defined as the duration of time from placement of the ultrasound probe on the skin to needle removal or palpation of anatomical landmarks to needle removal), number of needle-skin punctures (i.e., attempts), duration of needle-skin penetration, incidence of transient paresthesiae during block performance administration, and any other complications, including pain upon injection of the local anesthetic.

Block success was defined as diminished sensation to pinprick (sensory score ≤1) in each of the radial, ulnar, median, and musculocutaneous nerve distributions when measured 20 min after block performance. In cases where “block success” was not achieved after 20 min, a supplemental (“rescue”) nerve block could be administered in the block room, if necessary, at the discretion of the attending anesthesiologist. In the event of inadequate analgesia intraoperatively, a standardized algorithm was followed. First, the surgeon infiltrated the surgical skin site with 1–2% lidocaine or 0.25–0.5% bupivacaine without epinephrine. Next, fentanyl 25 μg iv was administered every 5 min as needed, to maximum 100 μg · hr⁻¹, and finally, conversion to general anesthesia if necessary. The algorithm for inadequate anxiolysis was administering propofol 10–20 mg every 5 min as needed, followed by conversion to general anesthesia if necessary. Readiness for surgery was defined as no requirement for supplemental nerve block, skin infiltration, or general anesthesia.

On postoperative day 7, telephone follow up was conducted by a blinded research assistant to inquire about potential block-related complications, such as paresthesiae, dysesthesiae, weakness, bruising, and pain. All complications were monitored until complete resolution.

Statistical analysis

The primary outcome measure for this study was block success, defined as diminished sensation to pinprick.
(sensory score ≤1) in each of the radial, ulnar, median, and musculocutaneous nerve distributions when measured 20 min after block performance. We hypothesized that ultrasound guidance increases the success rate of infraclavicular block from 68%-6 to 90% compared with a dual endpoint stimulation technique. Assuming z = 0.05 and β = 0.2 required a sample size of 106 patients (53 per group). Data were analyzed using SPSS version 11.0 for Windows (SPSS Inc., Chicago, IL, USA) and MedCalc version 10.4 (MedCalc Software, Mariakerke, Belgium). Data are presented as mean ± SD unless otherwise specified. Tests of significance included the Student's t test and the Mann–Whitney test of ranks for parametric and non-parametric testing of continuous variables, respectively. The Chi square test was used to analyze categorical data. Times to achieve sensory loss to pinprick and light touch were compared using the log rank test. Results were analyzed on an intent-to-treat basis. Statistical significance was established at P < 0.05.

Results

From December 6, 2005 to May 14, 2008, 128 patients were assessed for eligibility to participate in this study. Twenty-two patients were excluded (17 patients refused participation and 5 patients did not meet inclusion criteria). One hundred six patients were randomized (53 patients in the ultrasound group, 53 in the stimulation group). Three patients did not receive the study intervention and were excluded from data analyses. The reason for exclusion was inadequate time for block assessments (one patient in the ultrasound group and two patients in the stimulation group). In total, 103 patients (52 patients in the ultrasound group, 51 in the stimulation group) received their designated intervention and underwent data analyses. The procedure was abandoned in two patients in the stimulation group for failure to elicit two motor responses within the 20-min pre-specified time limit. These patients were considered as having normal sensation (i.e., no block) at all times. At the postoperative day 7 telephone call, 24 patients in the ultrasound group and 25 in the stimulation group were unavailable for follow up. Patient characteristics were similar between groups (Table 1).

Block success was achieved in 92% of patients in the ultrasound group compared with 80% in the stimulation group (difference 12%; 95% confidence intervals [CI] [-4 to 29%]; P = 0.18). Patients in the ultrasound group lost their sensation to pinprick in all four nerve distributions faster than patients in the stimulation group (P = 0.02) (Table 2). Loss of sensation to light touch (i.e., anesthesia) in all four nerve distributions was similar in both groups at each measured time interval (Table 2). In the ultrasound group, 85% of patients were ready for surgery 20 min after final injection compared with 65% of patients in the stimulation group (difference 20%; 95% CI [2–36%]; P = 0.04) (Table 3). Patients in the stimulation group required more fentanyl (53.0 ± 50.4 µg) for intraoperative analgesia than those in the ultrasound group (25.5 ± 31.6 µg) (difference 27.5 µg; 95% CI [10.9–44.0 µg]; P = 0.001). There was no difference between groups in intraoperative propofol consumption, i.e., ultrasound group 90 ± 131 mg and stimulation group 108 ± 135 mg (difference 18.8 mg; 95% CI [-33.9 to 71.5 mg]; P = 0.52).

The block performance time was significantly shorter in the ultrasound group (median 5 min; interquartile range

<table>
<thead>
<tr>
<th>Table 1 Patient characteristics</th>
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<tr>
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<tr>
<td>Gender (male/female)</td>
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<tr>
<td>Age (yr)</td>
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<tr>
<td>Height (m)</td>
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<tr>
<td>Weight (kg)</td>
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<tr>
<td>ASA I/II/III (n)</td>
</tr>
<tr>
<td>Surgical procedure (n)</td>
</tr>
<tr>
<td>Tendon</td>
</tr>
<tr>
<td>Bone</td>
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<tr>
<td>Nerve</td>
</tr>
</tbody>
</table>

Values are presented as number of patients, or mean ± SD

ASA American Society of Anesthesiologists physical status

<table>
<thead>
<tr>
<th>Table 2 Loss of sensation to pinprick and light touch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min Ultrasonic Stimulation P valuea</td>
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<tr>
<td>------------------------------------------</td>
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<tr>
<td>Loss of sensation to pinprick (n)</td>
</tr>
<tr>
<td>10</td>
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<tr>
<td>15</td>
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<td>20</td>
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<tr>
<td>Loss of sensation to light touch (n)</td>
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<td>15</td>
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<td>20</td>
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<td>25</td>
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<tr>
<td>30</td>
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</tbody>
</table>

Values are presented as number of patients with the corresponding percentages in parentheses

Min minutes after block performance
a Log rank test
Discussion

In our study, we found no statistically significant difference in success rate between ultrasound guidance and dual motor endpoint stimulation for infraclavicular block. Depending on the investigators’ definition of block success, the success rate of ultrasound-guided peripheral nerve blockade can vary, and this makes comparisons between similar studies difficult. Sauter et al.\textsuperscript{12} recently assessed the quality of infraclavicular block using ultrasound guidance (1–3 injections) and compared the results with single motor endpoint stimulation. These authors recorded equally high success rates in the ultrasound group (95%) and in the stimulation group (85%) \((P = 0.26)\) using criteria for success as either partial (“analgesia”) or complete (“anesthesia”) sensory block in all peripheral nerves distal to the elbow by 30 min following block performance.\textsuperscript{12} However, as these authors noted, their study was powered to detect a 5 min difference in block onset time and not a difference in block success. Therefore, a significant difference between ultrasound and stimulation for infraclavicular block success cannot be excluded based on Sauter et al.\textquoteright s study alone. Other previously published randomized studies comparing ultrasound with stimulation for infraclavicular block actually compared combined ultrasound-stimulation guidance with stimulation guidance alone. With close to complete sensory block in all nerves below the elbow by 30 min as their criterion for success, Gurkan et al.\textsuperscript{13} recently demonstrated that combined ultrasound-stimulation guidance (95%) has a success rate similar to that of single motor endpoint stimulation (93%). With block performance time as the primary outcome, Dingemans et al.\textsuperscript{14} compared ultrasound guidance alone with a single motor endpoint combined ultrasound-stimulation technique. With success defined as complete sensory block in the median, radial, ulnar, and musculocutaneous nerve distributions, the authors of this unblinded study reported a large difference in success between their groups (ultrasound 86%, stimulation 57%; \(P = 0.007\)).

Block performance time for infraclavicular block also varies widely depending on the definition used and the number of motor endpoints sought. In the present study, when block performance time was defined as the time between probe placement (ultrasound group) or landmark palpation (stimulation group) and needle removal, we found that ultrasound nearly halves block performance time compared with a dual motor endpoint stimulation technique. We purposefully included the “pre-scanning time” required to obtain and optimize the short-axis sonographic view of the cords, which, in our opinion, is inextricably linked to safe and successful ultrasound-guided infraclavicular block. With performance time defined as the time elapsed between needle insertion and needle removal, Dingemans et al.\textsuperscript{14} similarly demonstrated a shorter block performance time using ultrasound alone (3.1 ± 1.6 min) compared with a combined ultrasound-stimulation technique (5.2 ± 4.7 min) \((P = 0.006)\). In contrast, Sauter et al.\textsuperscript{12} found similar block performance times between the ultrasound (4.1 ± 1.3 min) and single motor endpoint stimulation (4.3 ± 1.3 min) \((P = 0.64)\) groups. However, when the “pre-scanning time” was excluded, Sauter et al.\textsuperscript{12} demonstrated a significantly shorter block performance time for the ultrasound group.

### Table 3 Intraoperative characteristics

<table>
<thead>
<tr>
<th></th>
<th>Ultrasound ((n = 52))</th>
<th>Stimulation ((n = 49))</th>
<th>Difference (%)</th>
<th>95% CI</th>
<th>(P) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Readiness for surgery</td>
<td>44 (85%)</td>
<td>32 (65%)</td>
<td>20</td>
<td>2 to 36%</td>
<td>0.04</td>
</tr>
<tr>
<td>Supplemental nerve block</td>
<td>7 (14%)</td>
<td>15 (31%)</td>
<td>17</td>
<td>−1 to 33%</td>
<td>0.06</td>
</tr>
<tr>
<td>Skin infiltration</td>
<td>0 (0%)</td>
<td>1 (2%)</td>
<td>2</td>
<td>−5 to 11%</td>
<td>1.00</td>
</tr>
<tr>
<td>General anesthesia</td>
<td>1 (2%)</td>
<td>1 (2%)</td>
<td>0</td>
<td>−8 to 9%</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Values are presented as number of patients with the corresponding percentages in parentheses. CI confidence intervals.
compared with the single motor endpoint stimulation group ($P = 0.003$). Finally, Gurkan et al.\textsuperscript{13} found that a combined ultrasound-stimulation technique (7.2 ± 1.0 min) prolonged block performance time compared with stimulation alone (6.4 ± 1.0 min) ($P < 0.05$), with performance time measured from the time of placing the ultrasound probe on the skin to the time of needle removal. Thus it appears from these studies and ours that, compared with ultrasound alone, seeking one or more motor endpoints— with or without ultrasound guidance—unnecessarily prolongs block performance time without adding any benefit with regard to block success.

Traditional teaching assumes that unintentional paresthesiae elicited during block performance stem from needle-nerve contact, and as such, should be avoided for fear of persistent neurological symptoms.\textsuperscript{15,16} Therefore, it is not surprising that nearly half of the patients in our ultrasound group complained of paresthesiae during block performance compared with only three patients in our ultrasound group. In a similar trial by Sauter et al., it is surprising and rather difficult to explain that 20% of patients in the ultrasound group experienced paresthesiae during block performance compared with only 2.5% of the stimulation group.\textsuperscript{12} One explanation may be that some providers use ultrasound to advance the needle tip as closely as possible to the nerve, i.e., a shorter needle tip-to-nerve distance than what would normally be achieved using stimulation guidance alone.\textsuperscript{17} Nonetheless, we found that the incidence of persistent paresthesiae is minimal by postoperative day 7, and no patient in our study reported paresthesiae persisting beyond 4 weeks.

The foremost limitation of the present study is inadequate power to exclude type II error from our primary outcome. Post hoc power analysis reveals that 258 patients per group would be required to detect a significant difference in block success rate. Nonetheless, the present study demonstrates statistically significant and clinically important differences in block performance time between groups that remain worthy of dissemination. Another limitation of our study is that our results are not generalizable to anesthesia providers of different ultrasound skill levels. For example, “pre-scanning” time likely varies indirectly with operator experience using ultrasound. Our results would have been more generalizable had we included providers with varying degrees of ultrasound experience rather than only experienced operators; however, ultrasound-guided infracuticular block is generally considered to be an intermediate technical skill that is not necessarily appropriate for the novice sonographer.

Finally, while all study patients were blinded to the most feasible extent, it is possible that some patients may have surmised their group allocation based on the presence or absence of muscle twitching during block performance.

In summary, this study found no statistically significant difference in success rate between ultrasound guidance and dual motor endpoint stimulation for infracuticular block. However, ultrasound guidance can shorten performance time and improve readiness for surgery compared with a dual motor endpoint stimulation technique for infracuticular block.

Acknowledgements This project was supported by a grant to Dr. Colin McCartney from the Physicians’ Services Incorporated Foundation (Toronto, ON, Canada) and the Canadian Anesthesiologists’ Society. Dr. Vincent Chan receives equipment support and honoraria from Philips Medical Systems, SonoSite\textsuperscript{8}, and GE Medical. Dr. Colin McCartney receives equipment support from GE Medical and Sonosite\textsuperscript{8} and honoraria from SonoSite\textsuperscript{8}.

Conflicts of interest None declared.

References


Reports of Original Investigations

Ultrasound guidance improves success rate of axillary brachial plexus block

[L’échoguidage améliore le taux de succès du bloc axillaire du plexus brachial]

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**Purpose:** The purpose of this study is to determine if real time ultrasound guidance improves the success rate of axillary brachial plexus blockade.

**Methods:** 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. Following administration of a standardized solution containing 2% lidocaine with 1:200,000 epinephrine and 0.5% bupivacaine (total 42 mL), sensory and motor functions were assessed by a blinded observer every five minutes for 30 min. A successful block was defined as complete sensory loss in the median, radial and ulnar nerve distribution by 30 min. The need for local and general anesthesia supplementation and post-block adverse events were documented.

**Results:** One hundred and eighty-eight patients completed the study. 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. Postoperatively, axillary bruising and pain were reported more frequently in Group NS.

**Conclusion:** This study demonstrates that ultrasound guidance, with or without concomitant nerve stimulation, significantly improves the success rate of axillary brachial plexus block.


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This article is accompanied by an editorial. Please see Can J Anesth 2007; 54: 165–70.
BRACHIAL plexus blockade is an excellent anesthetic option for upper limb surgery. Long lasting pain relief, a low incidence of nausea and vomiting, and expedited hospital discharge are some of the clinical advantages for outpatients. However, inconsistent block success remains one of the major limitations of brachial plexus blockade and can lead to an unplanned general anesthetic, increase material costs, and prolong operating room time. Another limitation is the potential for procedure-related complications such as nerve injury and unintentional vascular puncture. These disadvantages can be largely attributed to traditional nerve localization techniques which rely on surface anatomical landmarks, patient report of paresthesia, and/or elicitation of a motor response by electrical nerve stimulation.

In recent years, real time ultrasonographic guidance has been introduced as an aid to nerve localization for brachial plexus blockade in the interscalene, supraclavicular, and infraclavicular regions. While ultrasound has been reported to be useful for axillary block, outcome data on block success and patient safety from randomized clinical trials are lacking. The primary objective of this study was to determine if real-time ultrasound guidance improves the success rate of axillary brachial plexus block.

Methods

After institutional Research Ethics Board approval and written informed consent, patients scheduled to undergo elective hand surgery under axillary brachial plexus block took part in this randomized, controlled, double-blind study. Inclusion criteria were: 18–85 yr of age, ASA physical status I–III, 50–110 kg, 150 cm tall or greater, and English-speaking. Exclusion criteria were: any contraindication to brachial plexus anesthesia (e.g., local anesthetic allergy, local infection and coagulopathy), significant neurologic disorder of the upper extremity, significant psychiatric or cognitive disorder, and history of substance abuse and long-term opioid use. All block procedures were performed by a staff anesthesiologist or a fellow/resident under direct supervision. Once iv access was established and routine non-invasive monitoring (non-invasive blood pressure, 3 lead electrocardiogram, and pulse oximeter) applied, midazolam 1–2 mg iv was administered for anxiolysis as necessary. After skin sterilization with chlorhexidine, and skin infiltration with 1% lidocaine, a short bevel 2 inch, 22-G insulated needle (Stimuplex, Braun Medical, Bethlehem, PA, USA) was inserted for axillary block in an arm abducted 90° to the torso.

All patients were randomized by a computer-generated table into one of the three groups: 1) nerve stimulation (NS); 2) ultrasound (US); and 3) ultrasound plus nerve stimulation (USNS). The randomization sequence was concealed in sealed envelopes. A standardized local anesthetic solution consisting of 21 mL of 2% lidocaine with 1:200,000 epinephrine and 21 mL of 0.5% bupivacaine (total 42 mL) was injected. One third of the total dose (14 mL) was incrementally deposited around each of the three target nerves, i.e., ulnar, median, and radial nerves.

The block procedure was conducted according to the study group assignment. Patients in Group NS received an axillary block guided by a nerve stimulator (Stimuplex, Braun Medical, Bethlehem, PA, USA) with a stimulating frequency of 2 Hz, and a pulse width of 100 usec. A distal motor response in the hand was sought in the distribution of each of the median, ulnar and radial nerves, with a current threshold of 0.5 mA or less. Forearm pronation or thumb opposition was considered an acceptable distal motor response for median nerve stimulation, ring and little finger flexion for ulnar nerve stimulation, and wrist extension for radial nerve stimulation. However, a proximal motor response (triceps muscle contraction) was also accepted for radial nerve localization if this occurred. For blinding purposes, a “sham” ultrasound probe was applied to the axillary area and held by an assistant. The probe was connected to the ultrasound equipment in the stand-by mode.

Patients in Group US received an axillary block under ultrasound guidance using a linear 5–12 MHz probe (Figure 1A) and Philips HDI 5000 unit (Philips Medical Systems ATL Ultrasound, Bothell, WA, USA). The probe surface was covered by a sterile...
FIGURE 1B  A transverse sonogram showing the median (M), radial (R) and ulnar (U) nerves around the axillary artery (A) and the block needle (arrowheads) in contact with the median nerve.

FIGURE 1C  A schematic drawing of eight pie-chart sectors to describe nerve locations around the axillary artery (A).

FIGURE 1D  A transverse sonogram showing local anesthetic spread (LA) around the ulnar nerve (U); A = axillary artery.

transparent dressing and sterile gel was applied prior to scanning. Individual nerves, axillary vessels, and adjacent muscles (biceps, coraco-brachialis and triceps muscles) were identified in a transverse view (Figure 1B). The ultrasound probe was orientated consistently to display the biceps muscle on the left side of the sonogram screen (above the artery) and the triceps muscle on the right side (below the artery) (Figure 1B). Location of individual nerves was recorded according to a schematic drawing of eight pie-chart sectors (Figure 1C). The needle was advanced inline with the ultrasound beam until the needle tip was placed adjacent to each target nerve before local anesthetic was injected to produce a circumferential spread around each target nerve (Figure 1D).

In Group USNS, after nerve locations were examined, the needle tip was first positioned adjacent to each target nerve under ultrasound guidance before the nerve stimulator was turned on. The needle was further adjusted as needed to evoke a distal motor response at 0.5 mA or less. Again, proximal triceps muscle contraction was considered acceptable for radial nerve stimulation if this occurred. Local anesthetic was then injected to produce a circumferential spread.

An independent observer recorded the block procedure time, defined as the time from start (palpation of the axillary artery in Group NS, and ultrasound probe application in Groups US and USNS) to the end of local anesthetic injection. A blinded observer (not present during the block) assessed the onset and progression of sensory and motor anesthesia in the median, ulnar and radial nerve distributions every five minutes for 30 min. Sensory function was tested in the thenar eminence (median nerve innervation), the hypothenar eminence (ulnar nerve innervation) and the dorsal first web space (radial nerve innervation). Sensory anesthesia to pinprick was assessed using a 23G needle and graded as 2 = normal sensation, 1 = decreased or dull sensation, 0 = no sensation. Individual muscle groups were tested as follows: thumb opposition (median nerve), little finger flexion and finger abduction-adduction (ulnar nerve) and wrist and elbow extension (radial nerve). Motor function was graded as 2 = normal movement and power,
1 = weaker than baseline, 0 = no movement. Block success was defined as no sensation (score = 0) in all three target nerves at 30 min. After 30 min, anesthesia deemed inadequate was supplemented by a “rescue block” or a general anesthetic according to the attending anesthesiologist’s discretion.

Telephone follow-up was conducted on postoperative day two and seven to monitor for complications e.g., persistent paresthesia, bruising and pain in the axilla. Any persistent complication was followed weekly until complete resolution.

Data were summarized and analyzed using SPSS 10.0 for Windows. Results are reported as mean ± SD. Tests of significance included the t test for independent samples, Mann Whitney ANOVA of ranks for non-parametric data and Chi-square test for frequency count data. A P value < 0.05 was considered significant.

**Sample size calculation**

We hypothesized that ultrasound guidance would increase success rate from an estimated baseline of 80% to 95%. With a type 1 error of 5% and a type 2 error of 20%, sample size was estimated at 220 patients. An axillary block was considered successful if it provided complete sensory anesthesia in the distribution of all three target nerves. Secondary outcomes included the need for unplanned general anesthetic or a rescue block, the incidence of block related complications, and the time required to perform the block procedure.

**Results**

Two hundred and twenty-five patients were enrolled in this study. Seven patients were excluded due to cancelled surgery (n = 2), change in anesthetic plan (n = 2), incomplete patient information (n = 1), patient withdrawal from study (n = 1), and protocol violation (n = 1). Among the remaining 218 patients, 30 did not complete 30 min of assessment due to an early surgical start time, leaving 188 complete patient data sets available for analysis (Figure 2). Patient characteristics including age, height, weight, gender, body mass index, duration of surgical procedure, and iv intraoperative medications did not differ among study groups (Table I).

Patients in Groups US and USNS had a higher overall block success rate (82.8% and 80.7% respectively) than Group NS (62.9%) (P = 0.01 and 0.03 respectively, Table II). Blockade of each individual target nerve was also more successful in Groups US and

**TABLE I** Patient demographics and operative data (n = 188)

<table>
<thead>
<tr>
<th></th>
<th>NS (n = 62)</th>
<th>US (n = 64)</th>
<th>USNS (n = 62)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (male / female)</td>
<td>30 / 32</td>
<td>43 / 21</td>
<td>37 / 25</td>
<td>0.20</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>49.3 ± 14.6</td>
<td>44.3 ± 13.5</td>
<td>45.2 ± 13.0</td>
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<tr>
<td>Weight (kg)</td>
<td>74.9 ± 13.8</td>
<td>78.2 ± 18.9</td>
<td>79.6 ± 17.5</td>
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<tr>
<td>Height (cm)</td>
<td>167.0 ± 10.9</td>
<td>168.1 ± 23.8</td>
<td>169.7 ± 9.7</td>
<td>0.68</td>
</tr>
<tr>
<td>Body mass index (kg·m²)</td>
<td>27.0 ± 4.6</td>
<td>27.1 ± 5.1</td>
<td>27.7 ± 5.8</td>
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<tr>
<td>Surgical time (min)</td>
<td>50.8 ± 24.9</td>
<td>57.5 ± 28.5</td>
<td>55.8 ± 3.6</td>
<td>0.43</td>
</tr>
</tbody>
</table>

Intraoperative

<table>
<thead>
<tr>
<th>Medication</th>
<th>NS (n = 62)</th>
<th>US (n = 64)</th>
<th>USNS (n = 62)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>fentanyl dose (ug)</td>
<td>39.5 ± 50.1</td>
<td>42.7 ± 43.3</td>
<td>44.4 ± 50.5</td>
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<tr>
<td>propofol dose (mg)</td>
<td>51.7 ± 105.8</td>
<td>69.8 ± 117.9</td>
<td>81.0 ± 121.0</td>
<td>0.36</td>
</tr>
<tr>
<td>midazolam dose (mg)</td>
<td>1.2 ± 1.2</td>
<td>1.4 ± 1.7</td>
<td>1.3 ± 1.4</td>
<td>0.80</td>
</tr>
</tbody>
</table>

NS = nerve stimulator Group, US = real-time ultrasound guidance in the ultrasound Group and USNS = combined ultrasound and nerve stimulation Group.
USNS after 30 min (Table II). The minimum stimulating current (mean) was 0.4 ± 0.12 mA and 0.44 ± 0.08 mA for Groups US and NS respectively. The median nerve was most commonly visualized in sectors 7 and 8 (58%), the ulnar nerve in sectors 1 and 2 (87%) and the radial nerve in sectors 3 and 4 (70%). The radial nerve was the most frequently missed nerve in all three study groups (Table II). Triceps muscle contraction was elicited in a majority of the patients in Group NS (85%) and Group USNS (71%).

Surgical anesthesia was adequate without any supplementation in 95% and 92% of the patients in Groups US and USNS, respectively, as compared with 85.5% of patients in Group NS (P = 0.07 and 0.26 respectively). The block procedure time was significantly shorter in Group US (9.3 ± 4.0 min vs 11.2 ± 4.4 min for Group NS and 12.4 ± 4.8 min for Group USNS (P = 0.01, Table II). Major complications (e.g., unintentional intravascular injection and persistent neurological deficit) did not occur. Transient post-block paresthesia (< five days) was observed in 13 patients in both Groups US and NS and nine in Group USNS. Local bruising was detected in eight and two patients in Groups NS and US, respectively,
and none in Group USNS. Local axillary pain or discomfort was noted in ten, three, and three patients in Groups NS, US and USNS, respectively.

**Discussion**

Ultrasound is a relatively new tool for regional anesthesia. It requires investment of time and money for acquisition of new skills and equipment. Many anesthesiologists question the presumed benefits and demand proof of improved patient outcome before incorporating this new technology into their clinical practice. Our results suggest that ultrasound guidance, with or without nerve stimulation, improves the success rate of axillary brachial plexus block without an increase in procedure time when compared to nerve stimulation alone (complete sensory anesthesia in all three target nerves, 81–83% vs 62%). In this study, we chose complete pinprick anesthesia in all three nerves as the definitive endpoint for block success, yielding a lower block success rate in the 80% range for the ultrasound guided techniques. Importantly, however, the overall success rate of surgical anesthesia without any supplementation was considerably higher (highest in Group US, 95% vs 92% for Group USNS and 86% for Group NS).

The present study is one of the largest reported randomized controlled trials to date with a clear definition of brachial plexus block success. Schwenawer et al.\(^\text{15}\) reported complete anesthesia of the brachial plexus with fast onset following ultrasound guided axillary block in 46 patients. Among published comparative studies to date, most were small scaled, and failed to show improved block success with ultrasound based on assessment of surgical anesthesia. For example, Williams et al.\(^\text{16}\) reported adequate surgical anesthesia without rescue in 85% and 78% of patients receiving ultrasound and nerve stimulator guided supraclavicular blocks, respectively. Liu et al.\(^\text{17}\) reported success rates of 73% and 70% for ultrasound and nerve stimulator guided axillary blocks, respectively, and Marhofer et al.\(^\text{18}\) reported a 100% success rate for pediatric infraclavicular block guided by either technique. Soeding et al.\(^\text{19}\) compared ultrasound with landmark guidance and reported successful surgical anesthesia in 95% and 90% of patients, respectively. Although the overall success rate was not statistically different in these studies, ultrasound guidance was reported to shorten block procedure time,\(^\text{16}\) hasten block onset,\(^\text{18}\) improve block quality,\(^\text{16}\) prolong block duration\(^\text{18}\) and decrease block related complications.\(^\text{17,19}\)

Only one previously published study has shown a higher success rate with ultrasound guided axillary block. Sites et al.\(^\text{20}\) compared ultrasound guided perivascular injection with transarterial axillary block. Surgical anesthesia without the need for block supplementation was significantly more frequent in the ultrasound group (82%) than the transarterial group (54%). The incidence of complete sensory anesthesia at 30 min in all three nerves was 73% for ultrasound and 58% for the transarterial approach. In the present study, the success rate was much higher, 92–95% for surgical anesthesia and 81–83% for complete pinprick anesthesia at 30 min. Although ultrasound was used in both studies, local anesthetic placement was likely more accurate during a nerve targeted injection (in the present study) than a perivascular injection.

In the ultrasonographic study by Retzl et al.\(^\text{14}\), terminal branches of the brachial plexus were found in widely variable locations in the axillary region. The median nerve was most commonly found in sectors 7 and 8 (49%), the ulnar nerve in sectors 1–3 (91%) and the radial nerve in sectors 2 and 3 (58%). In the present study, we noted similar nerve locations relative to the axillary artery. Among the three nerves, we found visualization of the radial nerve and needle accessibility most challenging, because of its often deep location relative to the ulnar nerve or axillary artery. This may explain why the radial nerve was the most commonly missed nerve in the present study (incomplete sensory anesthesia at 30 min: 14%, 31% and 16% in Group US, NS and USNS respectively).

Clinical studies of axillary block have demonstrated that higher block success is achieved with triple stimulation (median, radial and musculocutaneous nerves) than with single or double stimulation techniques.\(^\text{21,22}\) Anatomical studies also show the presence of septae within the axillary sheath which are thought to act as a diffusion barrier to local anesthetic spread.\(^\text{23}\) Although visualization of septae is beyond the resolution of the ultrasound equipment we used, it is possible to observe the extent of local anesthetic spread in the axillary compartment under ultrasound. We find that, in most instances, local anesthetic spread is localized to the injected region immediately next to the target nerve without circumferential spread around the axillary artery. Our observation provides some support to the septae barrier concept, and helps to explain why a multiple injection technique results in higher success rates.

Contrary to our expectations, we failed to demonstrate a higher block success rate when nerve stimulation was added to ultrasound as a confirmatory tool. The mean threshold stimulating current was 0.4 ± 0.12 mA in Group USNS indicating needle to nerve proximity. However, the ultimate endpoint at the time of injection was circumferential local anesthetic
spread around individual target nerve and not a pre-
determined stimulating current threshold in Group
USNS. Our chosen injection endpoint – based pri-
marily on ultrasound visualization of the needle tip–
likely explains the lack of a difference in block success
between Groups US and USNS. We also failed to
achieve 100% block success in the ultrasound guided
groups. This is likely the result of mistaken nerve
identity in Group US and misinterpretation of local
anesthetic circumferential spread in Groups US and
USNS.

In conclusion, our study demonstrates that real
time ultrasound guidance, with or without nerve
stimulation, significantly improves the success rate of
axillary brachial plexus block with a low incidence of
supplementary anesthesia.

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my of the brachial plexus sheath: implications for anes-
Purpose: Ultrasound (US) is being used increasingly to guide needle placement during axillary brachial plexus blockade (AXB). This retrospective study investigated whether US guidance can increase the success rate, decrease block onset time, and reduce local anesthetic (LA) volume for AXB compared to a traditional (TRAD) approach, namely, peripheral nerve stimulation (PNS) and transarterial (TA) techniques.

Methods: The anesthetic records, operative reports, discharge summaries, and surgical consultation notes of all patients who had undergone AXB for surgical anesthesia at the Toronto Western Hospital, between October 2003 and November 2006 were, retrospectively reviewed for evidence of block success and associated complications. Block success was defined as the achievement of surgical anesthesia without additional LA supplementation.

Results: Among the 662 patients, 535 patients underwent AXB using US guidance (US group), and 127 using TRAD techniques (TRAD group), namely, 56 using PNS (PNS subgroup) and 71 using the TA technique (TA subgroup). The block success rate was higher in the US group compared to the TRAD group (91.6% vs 81.9%, P = 0.003). The LA volume used for AXB was less in the US group compared to the TRAD group (39.8 ± 6.4 mL vs 46.7 ± 17.1 mL, P < 0.0001). Ultrasound group patients spent less time in the block procedure room than those in the TRAD group (30.6 ± 14.2 min vs 40.1 ± 27.3 min, P < 0.0001). When analyzed by subgroup, the US group demonstrated significantly greater success and shorter duration in the block room compared to the PNS subgroup, but not the TA subgroup. Complications (inadvertent intravenous LA injection, and transient neuropathy) were lower in the US group compared to the TRAD group (0.37% vs 3.15%, P = 0.014).

Conclusions: Our results suggest that US-guided AXB may improve block success, reduce the local anesthetic volume used, and shorten the time spent in the block room compared to traditional nerve localization techniques.

Objectif : L’ultrason (US ou échoguidage) est de plus en plus utilisé pour guider le positionnement de l’aiguille pendant le bloc du plexus brachial par approche axillaire (AXB). Cette étude rétrospective a cherché à déterminer si l’échoguidage peut améliorer le taux de réussite, raccourcir le délai d’installation et réduire le volume d’anesthésique local (AL) pour l’AXB par rapport à une approche traditionnelle (TRAD), c’est-à-dire aux techniques de stimulation des nerfs périphériques (PNS) et par transfusion artérielle (TA).

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Méthode : Les dossiers anesthésiques, les dossiers d’opération, les résumés de congrès et les notes de consultation chirurgicale de tous les patients subissant un AXB dans le cadre d’une anesthésie chirurgicale au Toronto Western Hospital entre octobre 2003 et novembre 2006 ont été évalués rétrospectivement afin de trouver des données probantes quant à la réussite du bloc et aux complications associées. La réussite d’un bloc était définie comme l’obtention d’une anesthésie chirurgicale sans addition supplémentaire d’AL.

Résultats : Parmi les 662 patients dont les dossiers ont été évalués, 535 patients ont subi un AXB échoguidé (groupe US), et 127 à l’aide de techniques traditionnelles (groupe TRAD), dont 56 patients à l’aide de PNS (sous-groupe PNS) et 71 à l’aide de la technique TA (sous-groupe TA). Le taux de réussite du bloc était plus élevé dans le groupe US comparé au groupe TRAD (91,6 % vs 81,9 %, P = 0,003). Le volume AL utilisé pour l’AXB était moins élevé dans le groupe US par rapport au groupe TRAD (39,8 ± 6,4 mL vs 46,7 ± 17,1 mL, P < 0,0001). Les patients du groupe échoguidé ont passé moins de temps en salle d’anesthésie régionale que ceux du groupe TRAD (30,6 ± 14,2 min vs 40,1 ± 27,3 min, P < 0,0001). Lorsque les résultats ont été analysés par sous-groupe, le groupe US a montré un taux de réussite significativement plus élevé et un séjour plus court en salle d’anesthésie régionale par rapport au groupe PNS, mais non par rapport au groupe TA. Les complications (injection intraveineuse involontaire d’AL et neuropathie temporaire) étaient moins courantes dans le groupe US que dans le groupe TRAD (0,37 % vs 3,15 %, P = 0,014).

Conclusions : Nos résultats suggèrent qu’un bloc du plexus brachial par approche axillaire échoguidée pourrait améliorer le taux de réussite du bloc, réduire le volume d’anesthésique local utilisé, et réduire le temps passé en salle d’anesthésie régionale par rapport aux techniques traditionnelles de localisation des nerfs.

The axillary approach to brachial plexus blockade (AXB) can provide superior pain relief, reduce nausea and vomiting, and expedite hospital discharge compared to general anesthesia for hand surgery.1 Given its record of success and safety, as well as the case with which the technique is learned and performed, AXB is the most commonly performed peripheral nerve block by members of the Society for Ambulatory Anesthesia.2 The traditional (TRAD) approach used to localize the brachial plexus includes the use of surface anatomic landmarks, seeking paresthesias, and the elicitation of motor responses by electrical nerve stimulation. These TRAD techniques can result in inconsistent success rates,3 the need for a “rescue block,”4 or an unplanned general anesthetic,5 all with increased costs and time requirements.4 Further, blind techniques for AXB may increase the potential for complications, including nerve injury and vascular puncture.5

Real time ultrasonographic (US) guidance has recently gained tremendous popularity for nerve localization. Despite the recent upsurge in interest, a critical review of the literature reveals that the evidence in favour of improved success with US, compared to traditional nerve localization techniques, is wanting.3,4,6–8 Existing randomized controlled trials support that US can hasten AXB performance and onset times as well as improve block ‘quality’ and duration,3,4,6,8 but the ultimate question of improved block success (albeit the definition of ‘success’ can be highly variable) remains unresolved. Chan et al.9 as well as Liu et al.8 both demonstrated improved success rates using US compared to peripheral nerve stimulation (PNS) for AXB. In contrast, Casati et al.9 found no difference between the two guidance modalities. Large-scale outcome data to establish whether or not US guidance can improve the success rate of peripheral nerve blockade, in general, and AXB in particular, are currently lacking.5 The objective of the present study was to retrospectively examine the success rates of US guidance, compared to traditional nerve localization techniques, for AXB at our home institution. We hypothesized that US guidance can improve the success compared to traditional techniques.

Methods
After obtaining Institutional Ethics Review Board approval, medical records of all patients who had undergone AXB for surgical anesthesia at the Toronto Western Hospital for hand, wrist, or elbow surgery, between October 2003 and November 2006, were reviewed. The AXBs were performed either under US-guidance7 or using TRAD, specifically, multiple injection PNS11 or the transarterial (TA)12 technique. Peripheral nerve stimulation-guided AXB was performed using a nerve stimulator (Stimuplex®, B. Braun Medical, Bethlehem, PA, USA) with a stimulating frequency of 2 Hz, and a pulse width of 100 µsec. A distal motor response in the hand was sought in the distribution of each of the median, ulnar, and radial nerves, with a current threshold of 0.5 mA or less. Transarterial-guided AXB was performed using a 23G hypodermic needle (BD Medical, Franklin Lakes, NJ, USA) and 1.5% lidocaine 10 mg kg⁻¹, with 1:200,000 epinephrine. Ultrasound guidance became the nerve localization method of choice for AXB at our institution in mid-2004. At the Toronto Western Hospital, US-guided AXB is routinely performed using a 22G insulated needle (Stimuplex, B. Braun Medical, Bethlehem, PA, USA) and nerve stimulator as adjunctive
confirmation of nerve identity, but not necessarily needle-nerve proximity. Local anesthetic (LA) was injected to produce a circumferential spread around the median, ulnar, and radial nerves. A 50:50 mixture of 2% lidocaine and 0.5% bupivicaine with 1:200,000 epinephrine is the most commonly used LA for PNS- and US-guided AXB. The volume of LA used most often for either PNS- or US-guided AXB was 40 mL.

For each patient, the Toronto Western Hospital regional anesthesia electronic database (created in October 2003), intraoperative anesthetic record, postoperative anesthetic record, and surgeon’s preoperative consultation, intraoperative report, and follow-up clinic notes were reviewed, in order to determine block success and to identify any associated major complications (e.g., unintentional intravascular injection and persistent neurological deficit). Axillary brachial plexus blockade success was graded as complete (no LA supplementation or ‘rescue block’ required for surgical anesthesia), incomplete (LA supplementation or ‘rescue block’ required), or failed (general anesthesia required).

According to our routine clinical practice, all patients who receive regional anesthesia for surgery received midazolam and/or low-dose propofol infusion, intraoperatively, as needed for anxiolysis. Each AXB was performed by one of 11 attending staff regional anesthesiologists, or one of 43 regional anesthesia trainees (fellows or residents) under direct staff supervision in our block room.

All AXBs were administered in our “block room” – a monitored setting where patients receive regional anesthesia prior to entering the main operating room for their surgical procedures. The duration of the time spent in the block room was defined as the number of minutes elapsed from initial arrival of the patient into the room, to completion of the block. This time period not only encompassed block performance time, but also included patient preparation time and block assessment time. The duration of time spent in Phase I recovery (high acuity monitoring) and Phase II recovery (lower acuity monitoring), was defined as the number of minutes for which the patient was present in each of these locations.

### Statistical analysis

Data were analyzed by using MedCalc for Windows, version 9.3.7.0 (MedCalc Software, Mariakerke, Belgium). Differences in proportions were compared using the Chi-squared test for trend. Comparison of means was analyzed using the t test. The software implemented algorithms to correct for heterogeneity of variances between every two groups when necessary. Significance was assumed at $P < 0.017$, using the Bonferroni correction for multiple comparisons. In this study, the Bonferroni correction was used to determine the $P$-value for multiple comparisons of different endpoints and outcomes between the different groups (i.e., US, TA and PNS groups). We limited the utilization of such mathematical corrections of the

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**Table I  Patient characteristics**

<table>
<thead>
<tr>
<th></th>
<th>US group $(n = 535)$</th>
<th>TRAD group $(n = 127)$</th>
<th>$P$-Value</th>
<th>PNS subgroup $(n = 56)$</th>
<th>$P$-Value</th>
<th>TA subgroup $(n = 71)$</th>
<th>$P$-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male / Female $(n)$</td>
<td>297 / 238</td>
<td>73 / 54</td>
<td>0.762</td>
<td>34 / 22</td>
<td>0.546</td>
<td>39 / 32</td>
<td>0.972</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>47.4 ± 14.9</td>
<td>44.6 ± 14.8</td>
<td>0.057</td>
<td>45.2 ± 14.8</td>
<td>0.293</td>
<td>44.2 ± 14.9</td>
<td>0.090</td>
</tr>
<tr>
<td>BMI $(n)$</td>
<td>Less than 25</td>
<td>176 / 41</td>
<td></td>
<td>19 / 22</td>
<td></td>
<td>22 / 20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25 - 30</td>
<td>182 / 40</td>
<td></td>
<td>20 / 20</td>
<td></td>
<td>20 / 20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30.1 – 40</td>
<td>124 / 32</td>
<td></td>
<td>14 / 18</td>
<td></td>
<td>18 / 18</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; 40</td>
<td>21 / 1</td>
<td></td>
<td>0 / 1</td>
<td></td>
<td>1 / 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unknown</td>
<td>32 / 13</td>
<td></td>
<td>3 / 10</td>
<td></td>
<td>10 / 10</td>
<td></td>
</tr>
<tr>
<td>Surgical site $(n)$</td>
<td>384 / 104</td>
<td>50 / 44</td>
<td>0.413</td>
<td>0.564</td>
<td>0.104</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hand</td>
<td>123 / 20</td>
<td></td>
<td>5 / 15</td>
<td></td>
<td>15 / 15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wrist</td>
<td>26 / 1</td>
<td></td>
<td>0 / 1</td>
<td></td>
<td>1 / 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Elbow</td>
<td>2 / 2</td>
<td></td>
<td>1 / 1</td>
<td></td>
<td>1 / 1</td>
<td></td>
</tr>
</tbody>
</table>

*Significant difference ($P < 0.017$) compared to US group. $n$ = number of patients; BMI = body mass index; PNS = peripheral nerve stimulation technique; TA = transarterial technique; TRAD = traditional blind nerve localization technique; US = ultrasound-guided technique.
Results

Seven hundred and eighty-five patients underwent AXB for surgical anesthesia during the specified time period. One hundred and twenty-three patients were included in the analysis. However, retrospective statistical power analysis was performed using the software, G*Power V3.0.8 (Franz Faul, Kiel University, Germany). Statistical power for the tests performed pertaining to the different outcomes that showed significant P-values all had powers of > 0.80.

P-value to situations where the same test was repeated in many sub samples, such as when the groups were stratified according to age, gender, technique applied, success rates, etc. Data are presented as numerical count (n) or as mean ± SD.

Because of the retrospective design of the study, there was no a priori sample size calculation (i.e., all patients in the data base satisfying the inclusion criteria were included in the analysis). However, retrospective statistical power analysis was performed using the software, G*Power V3.0.8 (Franz Faul, Kiel University, Germany). Statistical power for the tests performed pertaining to the different outcomes that showed significant P-values all had powers of > 0.80.

TABLE II  Outcome measures following ultrasound-guided axillary brachial plexus block compared to traditional nerve localization techniques

<table>
<thead>
<tr>
<th></th>
<th>US group (n = 535)</th>
<th>TRAD group (n = 127)</th>
<th>P-Value</th>
<th>PNS subgroup (n = 56)</th>
<th>P-Value</th>
<th>TA subgroup (n = 71)</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Success (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complete</td>
<td>490 (91.6%)</td>
<td>104 (81.9%)</td>
<td>&lt; 0.0001</td>
<td>44 (78.6%)</td>
<td>&lt; 0.0001</td>
<td>60 (84.5%)</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Incomplete</td>
<td>27 (5.0%)</td>
<td>14 (11.0%)</td>
<td>&lt; 0.0001</td>
<td>7 (12.5%)</td>
<td>&lt; 0.0001</td>
<td>7 (9.9%)</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Failed</td>
<td>18 (3.4%)</td>
<td>-6.0% (1.1-12.8)</td>
<td>&lt; 0.0001</td>
<td>-7.5% (0.8-18.7)</td>
<td>&lt; 0.0001</td>
<td>-4.9% (-0.6-14.2)</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Local anesthetic volume (mL)</td>
<td>39.8 ± 6.4</td>
<td>46.7 ± 17.1</td>
<td>&lt; 0.0001</td>
<td>44.2 ± 16.8</td>
<td>0.0001*</td>
<td>56.9 ± 15.4</td>
<td>&lt; 0.0001*</td>
</tr>
<tr>
<td>Duration in block room (min)</td>
<td>30.6 ± 14.2</td>
<td>40.1 ± 27.3</td>
<td>&lt; 0.0001</td>
<td>46.4 ± 31.7</td>
<td>0.0001*</td>
<td>35.0 ± 22.1</td>
<td>0.023</td>
</tr>
<tr>
<td>Duration of surgery (min)</td>
<td>68.2 ± 32.5</td>
<td>67.0 ± 31.1</td>
<td>0.706</td>
<td>66.8 ± 32.7</td>
<td>0.759</td>
<td>67.2 ± 29.7</td>
<td>0.806</td>
</tr>
<tr>
<td>Phase I recovery (min)</td>
<td>49.9 ± 53.1</td>
<td>51.3 ± 26.8</td>
<td>0.658</td>
<td>44.6 ± 28.2</td>
<td>0.249</td>
<td>56.7 ± 24.6</td>
<td>0.095</td>
</tr>
<tr>
<td>Phase II recovery (min)</td>
<td>65.8 ± 57.9</td>
<td>72.1 ± 71.3</td>
<td>0.167</td>
<td>78.7 ± 97.2</td>
<td>0.050</td>
<td>65.9 ± 31.0</td>
<td>0.983</td>
</tr>
<tr>
<td>Major complications</td>
<td>2</td>
<td>4</td>
<td>0.014*</td>
<td>2</td>
<td>0.055</td>
<td>2</td>
<td>0.108</td>
</tr>
</tbody>
</table>

*Significant difference (P < 0.017) compared to US group. Difference is calculated as follows: % success in US group minus % success in other group. n = number of patients; CI = confidence interval; PNS = peripheral nerve stimulation technique; TA = transarterial technique; TRAD = traditional blind nerve localization technique; US = ultrasound-guided technique.
There were six cases of major complications associated with AXB. Five of these events involved intravascular LA injections during AXB: two were in the US group (frequency: 2/535, or 0.37%), two were in the TA subgroup (frequency: 2/71, or 2.82%), and occurred in the PNS subgroup (frequency: 1/56, or 1.79%). Of the two patients in the TA subgroup, one experienced a generalized seizure due to intravascular LA injection. This patient demonstrated no signs or symptoms of impending systemic LA toxicity prior to the sudden onset of generalized convulsions. The seizure was treated immediately with midazolam 2 mg iv followed by propofol 200 mg iv bolus. The patient’s hand surgery was cancelled, and following a period of same-day observation, the patient was discharged home without adverse sequelae. One patient in the PNS subgroup suffered postoperative AXB-associated neuropathy, which resolved spontaneously after approximately two months. The complication rate was significantly lower in the US group compared to the TRAD group (0.37% vs 3.15%, P = 0.014) (Table II).

**Discussion**

The benefits of peripheral nerve blockade for surgical anesthesia have long been undermined by its inconsistent success rates, variable block performance and onset times, as well as complications, all of which may well be related to the blind nature of traditional nerve localization techniques. Within the present study conditions, our retrospective data suggest that US guidance increases the success rate of AXB compared to traditional nerve localization techniques, despite smaller LA volumes used for US-guided AXB. Our retrospective results are similar to the findings from randomized controlled trials recently published by our group and by Liu et al., both of which demonstrated a significant improvement in success rates with US-guidance compared to PNS for AXB. In contrast, Casati et al. demonstrated no difference in success rates between US and PNS techniques when AXB is performed by expert regional anesthesiologists.

The majority of peripheral nerve blocks performed at our academic institution are performed by trainees, under the direct supervision of staff anesthesiologists, rather than by the staff anesthesiologists themselves. The present study demonstrated no significant difference between the success rates of AXBs performed by staff compared to trainees in the US or TRAD groups; therefore, the difference between our findings and those of Casati et al. cannot be fully explained by differences in the providers’ level of training alone.

Further, in contrast to Sites et al., we were unable to demonstrate a difference in success rates in subgroup analysis when comparing US-guided AXB to the TA technique. We did, however, find that significantly more LA volume was used for the TA technique compared to US-guided AXB, which may at least partially explain the equivalent success rates. Had the volumes of LA been fixed across all subgroups, it is plausible that we may have found a statistical difference in success rates between the US and TA groups.

Unlike our previously published randomized trial of US compared to PNS for AXB, the present study suggests that US may contribute to a reduction in the incidence of major complications compared to traditional techniques. Indeed, the strength of our retrospective review is its relatively large sample of US-guided AXBs. However, given the infrequency of such occurrences in modern anesthetic practice, considerably larger sample sizes would nonetheless be necessary to either confirm or refute this trend.

Finally, our study found that patients undergoing US-guided AXBs spent significantly less time in the block room, compared to those who underwent TRAD AXBs, which may be attributable to faster block onset and/or relative ease of block performance with US. A shorter duration of time spent in the block room may contribute to a reduction in perioperative costs.

**TABLE III** Success rates according to provider for ultrasound-guided axillary brachial plexus block compared to traditional nerve localization techniques*

<table>
<thead>
<tr>
<th></th>
<th>US-guided technique</th>
<th>TRAD-guided technique</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Staff performed</td>
<td>Trainee performed</td>
</tr>
<tr>
<td></td>
<td>(n = 374)</td>
<td>(n = 88)</td>
</tr>
<tr>
<td>Complete</td>
<td>78 (92.9%)</td>
<td>341 (91.2%)</td>
</tr>
<tr>
<td>Incomplete</td>
<td>3 (3.6%)</td>
<td>21 (5.6%)</td>
</tr>
<tr>
<td>Failed</td>
<td>5 (3.6%)</td>
<td>12 (3.2%)</td>
</tr>
</tbody>
</table>

|                  | Trainee performed   | P-Value |
|                  | (n = 13)            |         |
| Staff performed  | 12 (92.3%)          | 0.659   |
| Trainee performed| 1 (7.7%)            | 0.824   |

|                  | (n = 88)            |         |
| Staff performed  | 73 (83.0%)          | 0.745   |
| Trainee performed| 9 (10.2%)           |         |

*Block provider data was specified in 559 of 662 blocks. n = number of axillary brachial plexus blocks performed; TRAD = traditional blind nerve localization; US = ultrasound.
Our single-centre, retrospective study has several limitations. Because of the limited data available, we were unable to report on either block onset or block duration. Our retrospective review is also subject to incomplete charting; especially vulnerable is the frequency of complications, which could be underestimated due to potential lack of documentation. Further, as our practice patterns for hand surgery evolved from primarily TA AXB prior to 2003, to multiple endpoint PNS in 2004, and then to US-guided AXB in mid-2004 (and finally to US-guided suprACLavicular block in mid-2005), so too, did our primary choice of LA. While the LA type may have affected pharmacokinetic parameters such as block onset and duration, we do not believe that the differences in LA type substantially affected the pharmacodynamic parameters such as success and major complications, which were investigated in this study. Moreover, our unique data includes and reflects our early developmental stages (self-teaching and mutual learning) and preliminary experience with US-guided AXB, and yet still suggests superior success with US-guidance compared to traditional techniques. Lastly, it is unclear what role, if any, adjunctive nerve stimulation, which is routinely used in conjunction with US for AXB at our institution, played in improving the success rate of the US group compared to the TRAD group. Our recent prospective trial comparing US to PNS for AXB suggests that adjunctive nerve stimulation provides does not increase success rates.

In conclusion, this retrospective review suggests that US-guided AXB may improve block success, reduce the volume of LA used, and shorten the time spent in the block room, compared to traditional nerve localization techniques. Ultrasound guidance may also reduce the incidence of major AXB complications compared to traditional nerve localization techniques. Future large-scale, multi-institutional, prospective studies are needed, to assess whether or not US can reduce the incidence of major complications compared to traditional techniques.

References
The Sensitivity of Motor Response to Nerve Stimulation and Paresthesia for Nerve Localization As Evaluated by Ultrasound


Background and Objective: Seeking paresthesia and obtaining a motor response to an electrical stimulus are the two most common methods of nerve localization for the performance of peripheral-nerve blocks. However, these two endpoints do not always correlate, and the actual sensitivity and specificity of either method remains unknown. The objective of this study is to determine the sensitivity of paresthesia and motor response to electrical nerve stimulation as tools for nerve localization when a 22-gauge insulated needle is used for the performance of axillary-nerve block.

Methods: After IRB approval and informed consent, 103 patients were enrolled. Real-time ultrasonography was used as the reference test. After needle-to-nerve contact was confirmed by ultrasonography, the patient was requested to report the presence of paresthesia, and a nerve stimulator was used to seek a motor response, with a stimulating current of 0.5 mA or less.

Results: One patient was excluded from analysis because of protocol violation. Paresthesia was found to be 38.2% sensitive and motor response was 74.5% sensitive for detection of needle-to-nerve contact.

Conclusion: The very different and relatively low sensitivity of either technique may explain, in part, the lack of correlation previously reported between the 2 endpoints. Reg Anesth Pain Med 2006;31:445-450.

Key Words: Ultrasonography, Paresthesia, Electrical stimulation, Sensitivity.

Recently, interest in the practice of regional anesthesia has been renewed. This development may result, in part, from some of the benefits of regional anesthesia in the ambulatory surgical setting, which offers superior analgesia, fewer adverse events, and low rates of unplanned hospital admissions. However, regional anesthesia lacks the simplicity and consistent success that general anesthesia offers. Success of peripheral-nerve block depends on precise nerve localization and the delivery of local anesthetic in close proximity to the nerve. Until recently, paresthesia and electrical nerve stimulation have been the two main methods for nerve localization. The endpoint of an appropriate motor response to a current of 0.5 mA or less is considered acceptable for electrical nerve stimulation, which suggests that the needle is sufficiently close to the nerve. Considerable controversy exists over the correlation of paresthesia and nerve stimulation and which method is more precise and safer. The fact that motor response may not occur even when needle-nerve contact is suggested by elicitation of paresthesia has been well documented. To date, no other reference is available with which we can compare these two nerve-finding techniques to determine their sensitivities and specificities. However, the use of ultrasound has given us an imaging tool to identify peripheral nerves and determine needletip-to-nerve proximity. With this tool, the reliability of existing tests can be assessed. We designed the present study with the main objective of determining the sensitivity of both traditional techniques of nerve localization. In the context of this study, sensitivity is the proportion of patients with true needle-to-nerve contact, in whom a test result (motor response to nerve stimulation or presence of paresthesia) is positive. Specificity of a given test would be the proportion of patients without nee-
dle-to-nerve contact, in whom a test result is negative. To use these concepts, we must create a 2-column by 2-row table such as Table 1. However, in the present study, all patients are deemed to have true needle-to-nerve contact, as assessed by our reference test. Therefore, only sensitivities can be calculated, and not specificities.

### Methods

After Institutional Ethics Committee approval and written documentation of informed patient consent, 103 patients undergoing elective hand surgery under axillary brachial plexus block were studied. Inclusion criteria were 18 to 75 years of age, ASA I to III, and elective outpatient hand, wrist, or forearm surgical procedures that are amenable to brachial plexus anesthesia. Exclusion criteria included preexisting neuropathy as reported either by the patient or determined from previous medical records, local anesthetic drug allergy, cognitive dysfunction, language barrier, or any condition that would not allow for a valid informed consent. All axillary blocks were performed by staff anesthesiologists, fellows, or residents under supervision. Before axillary block, routine monitors, including electrocardiogram (ECG), noninvasive blood pressure (NIBP), and pulse oximetry were applied, and intravenous access was established in the contralateral arm. Anxiolysis was attained by intravenous administration of 1 to 3 mg of midazolam. Patients were maintained awake and responsive throughout the performance of the block.

After the operative arm was abducted and the elbow flexed to 90°, the axilla was prepared with antiseptic solution. A linear 12-MHz ultrasound probe (ATL HDI 5000; Philips, Bothell, WA) was prepared in a sterile fashion and then used to examine the anatomy of the neurovascular bundle (Fig 1). The axillary artery and the ulnar, radial, median, and musculocutaneous nerves were identified (Fig 2). After local skin infiltration with 1 mL of 2% lidocaine, a 2-inch, 22-gauge insulated needle (Stimuplex; Braun Medical, Bethlehem, PA) attached to a peripheral-nerve stimulator (Stimuplex; Braun Medical, Bethlehem, PA) advanced along the longitudinal axis of the ultrasound transducer so that the entire needle shaft would lie in the path of the ultrasound beam, and both needle shaft and tip could be visualized. The choice of the nerve to be contacted first was left to the discretion of the attending anesthesiologist performing or supervising the block procedure. This nerve was usually the one that was considered to be the most responsible for innervation of the surgical site. The needle insertion was performed from the lateral aspect of the arm (Fig 1) or from the medial aspect of the arm (Figs 2 and 3). This step was left to the discretion of the attending anesthesiologist, who would choose the insertion point that made access to the target nerve easier in each individual case. Once the needle was in contact with the nerve, as defined by the visual image of needle tip in contact with nerve and nerve movement upon contact, the patient was asked to report any feelings of paresthesia. Paresthesia was defined by the feeling of “an electric shock,” “pins and needles,” or “hit-

<table>
<thead>
<tr>
<th>Paresthesia</th>
<th>Needle-Nerve Contact</th>
<th>No Needle-Nerve Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present</td>
<td>True positive</td>
<td>False negative</td>
</tr>
<tr>
<td>Absent</td>
<td>False negative</td>
<td>True negative</td>
</tr>
</tbody>
</table>

Fig 1. Probe and needle position.

Fig 2. Sonographic anatomy of the axilla in contact with the ulnar nerve. A = axillary artery, N = needle, U = ulnar nerve, M = median nerve, R = radial nerve, MC = musculocutaneous nerve, B = biceps muscle, CB = coracobrachialis muscle, T = triceps muscle, H = humerus.
ting your funny bone.” If paresthesia occurred, its location was recorded. With the needle in contact with the nerve and under continuous ultrasound imaging, the nerve stimulator was then switched on. The stimulus frequency was 2 Hz, and the pulse width was 100 μs. The current amplitude was gradually increased to elicit a motor response or until the current reached a maximum of 2.0 mA. The minimum threshold-stimulating current and the type of motor response were recorded.

Thereafter, 15 mL of local-anesthetic solution were injected around the target nerve in 2-mL to 3-mL increments, to ensure adequate local-anesthetic spread (Fig 3). The remaining 3 nerves were blocked individually. A total of 40 to 60 mL of local anesthetic was used (Fig 4). The local-anesthetic solution used was 1.5% to 2% lidocaine, with 1:200,000 epinephrine alone or mixed in a 50:50 proportion with 0.5% bupivacaine or 0.5% ropivacaine. After the injections were complete, block onset and progression were monitored at 5-minute intervals. A simple 3-point scale was used to assess motor and sensory block: complete, partial, or absent. Pinprick sensation was tested with a 23-gauge hypodermic needle in each nerve distribution. For the purpose of the study, only the first nerve that was contacted and subsequently stimulated was considered the “test nerve.” This practice was to ensure a lack of any local anesthetic near the test nerve at the time of evaluation of paresthesia and nerve stimulation. When subsequent nerves are approached after local anesthetic has been injected at one location, the response of paresthesia and motor responses could conceivably be attenuated, and, therefore, this information was not included for analysis.

Statistical Analyses

Descriptive analyses were performed by application of SAS version 8.0 (SAS Institute Inc., Cary, NC). Continuous variables were summarized as mean ± standard deviation unless stated otherwise. Categorical variables were reported with the number of observations and percentage from totals. Sensitivity was determined as

true positives/(true positives + false negatives)

When the sensitivity of paresthesia was determined, a true positive was considered to be the presence of paresthesia when needle-to-nerve contact was confirmed by ultrasonography. A false negative was the absence of paresthesia when needle-to-nerve contact was confirmed by ultrasonography. For determination of the sensitivity of motor response to nerve stimulation, a true positive was defined as a motor response to nerve stimulation with a current of 0.5 mA or less, when needle-to-nerve contact was confirmed by ultrasonography. A false-negative case was the absence of such motor response under those conditions.

Results

Of the 103 patients recruited in this study, 1 patient was excluded from analysis because of protocol violation. This patient received only 5 mL of

Fig 3. Spread of local-anesthetic solution as a hypoechoic area that surrounds the ulnar nerve. U = ulnar nerve, A = axillary artery, N = needle.

Fig 4. Midazolam dose in paresthesia-positive and paresthesia-negative groups.
local anesthetic around the first nerve contacted. Final analysis was performed in the remaining 102 patients. Patient demographics are summarized in Table 2. The first nerve contacted was the median nerve in 75 patients (72.8%), the ulnar nerve in 17 patients (16.5%), the radial nerve in 6 patients (6.8%), and the musculocutaneous nerve in 4 patients (3.9%) (Table 3). Although the median nerve seems to be overrepresented as a target nerve, it is the nerve most responsible for the surgical site in a large number of patients, and not selected because of a systematic bias.

The sensitivity of paresthesia when a 22-gauge, shielded, short-beveled needle is used with first contact was found to be 38.2% because only 39 patients reported paresthesia upon needle-to-nerve contact (Table 4). Paresthesia was described as “pins and needles” by 34 patients (87%), as an “electric shock” by 4 patients (10%), and as “annoying pain” by 1 patient (3%). The sensory distribution of paresthesia was consistent with the target nerve. In all cases, paresthesias were reported upon direct questioning. No cases of spontaneous reports were seen. Also, care was taken to question about the presence of paresthesia, once needle-to-nerve contact only and not by the electrical current applied. The average dose of midazolam administered was similar in patients who reported paresthesia and those who did not (Fig 4). No other apparent differences existed between those patients who reported and those who did not report paresthesia. Demographic data, target nerves, type of motor response, and minimum currents were all comparable (Table 5).

The sensitivity of nerve stimulation to produce a motor response at a current of 0.5 mA or less and a pulse duration of 100 μs was found to be 74.5%, as 76 patients had a positive response (Table 6). The remaining 26 patients required currents of up to 1.0 mA to obtain a motor response. The cumulative rates of positive responses to increased electrical-current amplitude are shown in Figure 5.

At 30 minutes, 97% of patients (n = 99) had complete sensory block in the distribution of the test nerve, 1% (n = 1) had an incomplete block (radial nerve), and 2.0% (n = 2) did not have any sensory block in the distribution of the test nerve (median and ulnar nerves, respectively).

Motor block in the distribution of the test nerve was complete in 92% of patients assessed (n = 70 of 76) and partial in the remaining 8% of patients (n = 6 of 76). Although every patient was assessed for the first 30 minutes at 5-minute intervals, 26 patients had splints or extensive sterile bandages that precluded motor assessment.

Discussion

This study was designed to determine the sensitivity of paresthesia and electrical nerve stimulation for identification of needle-to-nerve contact during the performance of peripheral-nerve blocks by use of a 22-gauge insulated needle. To our knowledge, this study is the first study that attempts to quantify the sensitivity of the two most common methods of nerve localization in an objective way, when compared with a separate reference test.

Table 2. Patient Demographics

| Age (years) | 46.2 ± 13.4 |
| Gender (male/female ratio) | 1.55 |
| BMI (kg/m²) | 27.1 ± 5.2 |
| Diabetes | n = 3 |

Table 3. First Nerve Contacted (test nerve)

<table>
<thead>
<tr>
<th>Nerve</th>
<th>Number of Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>75</td>
</tr>
<tr>
<td>Ulnar</td>
<td>17</td>
</tr>
<tr>
<td>Radial</td>
<td>6</td>
</tr>
<tr>
<td>Musculocutaneous</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>102</td>
</tr>
</tbody>
</table>

Table 4. Incidence of Paresthesia

<table>
<thead>
<tr>
<th>Paresthesia Results</th>
<th>Positive Ultrasound Result (needle-to-nerve contact)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present (true positives)</td>
<td>39</td>
</tr>
<tr>
<td>Absent (false negatives)</td>
<td>63</td>
</tr>
<tr>
<td>Total</td>
<td>102</td>
</tr>
</tbody>
</table>

Table 5. Comparison Between Paresthesia Positive and Negative Groups

<table>
<thead>
<tr>
<th></th>
<th>Paresthesia</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td>0.34</td>
</tr>
<tr>
<td>Female (n = 40)</td>
<td>27 (43%)</td>
<td>13 (33%)</td>
</tr>
<tr>
<td>Male (n = 62)</td>
<td>36</td>
<td>26</td>
</tr>
<tr>
<td>Target nerve</td>
<td></td>
<td>0.44</td>
</tr>
<tr>
<td>Median (n = 75)</td>
<td>48 (76%)</td>
<td>27 (69%)</td>
</tr>
<tr>
<td>MCN (n = 4)</td>
<td>2 (3%)</td>
<td>2 (5%)</td>
</tr>
<tr>
<td>Radial (n = 6)</td>
<td>4 (6%)</td>
<td>2 (5%)</td>
</tr>
<tr>
<td>Ulnar (n = 17)</td>
<td>9 (14%)</td>
<td>8 (21%)</td>
</tr>
<tr>
<td>Motor response</td>
<td></td>
<td>0.54</td>
</tr>
<tr>
<td>Distal (n = 37)</td>
<td>24 (39%)</td>
<td>13 (33%)</td>
</tr>
<tr>
<td>Proximal (n = 63)</td>
<td>37</td>
<td>26</td>
</tr>
<tr>
<td>BMI</td>
<td>27.2 ± 5.4</td>
<td>26.8 ± 4.8</td>
</tr>
<tr>
<td>Minimum current</td>
<td>0.45 ± 0.15</td>
<td>0.39 ± 0.16</td>
</tr>
</tbody>
</table>
Our choice of reference test was based on the ability of ultrasound to provide real-time, high-resolution images of the regional anatomy, including the identification of the target nerve and blocking needle and assessment of local anesthetic spread. Also, some early data from small prospective randomized trials suggest a higher success rate of nerve block when ultrasonographic guidance is used, which would support a higher precision of nerve localization. In addition, in the present study, 97% of patients developed complete sensory block in the territory of the target nerve within 30 minutes. In our opinion, this high rate of complete sensory block supports the selection of real-time ultrasound guidance as a reference test.

Our study has several important limitations. First, and most important, the choice of ultrasound imaging as a reference test can be argued against. Ultrasonography is one of the most operator-dependent imaging techniques, and the interpretation of the images has a subjective component that could limit the usefulness of this technique as an "objective" reference test. Likewise, our definition of needle-to-nerve contact has a subjective component because the operator who interprets the image determines that the tip of the needle is in direct contact with the target nerve. A second important limitation is that the study was designed in such a way as to calculate sensitivities but not specificities. As a consequence, negative and positive predictive values cannot be calculated. Third, short-beveled insulated needles were used. These needles are the most commonly used when a nerve stimulation technique is used for nerve localization. However, they have been shown to cause a lower incidence of paresthesia than noninsulated needles, which are most often used during pure paresthesia-seeking techniques. Therefore, our results are only applicable to clinical situations in which a short-bevel insulated needle is used. The sensitivity of paresthesia may conceivably be higher if a long-bevel or a noninsulated needle is used. Another limitation is that the type of local-anesthetic solution was not standardized. In our opinion, this limitation is not a major shortcoming of the study, because the main objective is to compare the sensitivities of the different nerve-finding modalities, as compared with ultrasound imaging. All the data needed to calculate these results are obtained before the injection of any local anesthetic. Also, all the solutions used are expected to provide satisfactory block within 30 minutes of injection, if the needle location is correct. Finally, the patients in our study received an axillary approach to the brachial plexus, with 4 separate injections. Therefore, part of the local anesthetic intended for one of the other 3 nerves possible found its way to the target nerve. Therefore, the reported success rate of 97% for the target nerve should be interpreted with caution.

The occurrence of 1 case of incomplete block and 2 cases of no block may seem surprising. We should remember, however, that the use of ultrasonographic guidance requires the interpretation of images in real time by an operator who ultimately makes a conscious decision to accept or reject the needle position as correct and the local-anesthetic spread as the desired one. An incorrect appreciation of the endpoint (in this case the image) may have been made by the operator.

In this model, the sensitivity of paresthesia with an insulated needle was found to be 38.2%, whereas the sensitivity of a motor response with 0.5 mA or less was 74.5%. This outcome suggests that, under the conditions described in this study, both the elicitation of paresthesia and motor response to electrical nerve stimulation have a low sensitivity for localizing nerves. This finding has clear implications for clinical practice. We can infer that if ultrasound imaging had not been used, many instances would have occurred in which the needle would have been in direct contact with the target nerve, which would have been considered a negative or an inadequate response because of the absence of traditional endpoints. This result has potential implications for safety.

Regarding the motor response to nerve stimulation, all the “false-negative” patients showed a motor response with currents between 0.5 and 1.0 mA. The temptation is to conclude that all we need to do to improve the sensitivity of this method is to raise the

<table>
<thead>
<tr>
<th>Motor Response Results</th>
<th>Positive Ultrasound Result (needle-to-nerve contact)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present (true positives)</td>
<td>76</td>
</tr>
<tr>
<td>Absent (false negatives)</td>
<td>26</td>
</tr>
<tr>
<td>Total</td>
<td>102</td>
</tr>
</tbody>
</table>

Table 6. Motor Response to Nerve Stimulation Less Than 0.5 mA

Fig 5. Cumulative rates of motor response.
required minimum current from 0.5 to 1.0 mA. However, as with any other diagnostic test, once we raise the threshold we consider a positive response, although we can increase the sensitivity of the technique (fewer false negatives), we will be decreasing its specificity (more false positives). We can only speculate about this point because the current study has been designed to look at sensitivity only.

No randomized controlled trials compare the complications of these two traditional methods, but case reports and other available data suggest that nerve injury can occur with either method.9,10 The correlation of paresthesia and motor response to electrical nerve stimulation is not complete.5,11 Urmey and Stanton5 found no motor response to electrical nerve stimulation in 70% of patients after eliciting paresthesia. Similarly, Choyce et al.11 found dissociation between sensory and motor response in 30% of patients undergoing axillary block. As paresthesia was used as the initial endpoint for nerve localization, one of the reasons suggested for the discrepancy in eliciting sensory and motor response was operator or patient movement that caused needle displacement.12,13 Ultrasound imaging allows direct visualization of the needle as it approaches the nerve.14 As the needle-to-nerve contact was constantly visualized, we were able to ensure that needle position was maintained.

In the present model, the elicitation of paresthesia had a sensitivity of 38.2% for detection of needle-to-nerve contact. The presence of a motor response to electrical nerve stimulation with a current less than 0.5 mA showed a sensitivity of 74.5%. This very different and relatively low sensitivity of either test could explain, in part, the lack of correlation previously reported between the 2 endpoints. Future research into this question might involve a single-nerve model and include the assessment of both sensitivities and specificities, as well as positive and negative predictive values, to better define the accuracy and clinical value of paresthesia and motor response to electrical nerve stimulation as nerve-finding techniques.

References

Evidence Basis for the Use of Ultrasound for Upper-Extremity Blocks

Colin J.L. McCartney, MBChB, Lisa Lin, MBBS, and Uma Shastri, MD

Abstract: This article qualitatively assesses and summarizes randomized, controlled studies regarding benefits of ultrasound (US) for brachial plexus block and also examines those studies that have compared different brachial plexus block techniques using US.

Studies were identified by a search of PUBMED and EMBASE databases using the MeSH terms "anesthetic techniques, brachial plexus," and "ultrasound." Included studies were limited to randomized trials that compared a US technique with another accepted method of performing brachial plexus block or those studies that compared 2 different US-guided techniques. Studies were further classified according to methodological quality using accepted methods. Quality scores were compared using Mann-Whitney U test, and significance assumed at $P < 0.05$.

Twenty-five studies met inclusion criteria, with 19 studies comparing US techniques with other nerve location methods and 6 studies comparing different US techniques. Of the former, there was convincing evidence to support the use of US, with 15 of 19 studies demonstrating improved outcomes compared with existing techniques.

Ultrasound provides significant advantages when performing brachial plexus block including faster sensory block onset and greater block success.

METHODS

Search Strategy

Studies were identified in a search of PUBMED and EMBASE (between July 1991 and August 2009) by using the MeSH terms "anesthetic techniques, brachial plexus," and "ultrasound." The reference section of eligible articles was then examined for relevant publications. Relevant studies that examined the use of US for upper-extremity blocks were reviewed. Inclusion criteria included any randomized trial that had compared the use of US with any preexisting technique for upper-extremity block or any randomized trial that had compared 2 different techniques of US-guided brachial plexus block. Randomized studies where different local anesthetic volumes were assessed or different blocks using different nerve location methods for each block were not included. Letters to the editor, abstracts, non-peer-reviewed studies, case reports, and case series where no comparison was made were not included.

Three reviewers independently performed the literature searches and assessed all identified full articles for inclusion. These criteria included independently assessing each article with regard to type of randomization, blinding, brachial plexus block technique, volume, type and concentration of local anesthetic, type of surgery, performance time or number of needle passes, block onset, block success (requirement for supplemental local or general anesthesia), and procedure-related pain and other adverse effects. Studies were classified supportive of the US technique if any of the above measured end points demonstrated a significant difference between groups favoring that group and negative if no difference between groups was observed or if the study favored the alternative (non-US) technique. The criteria for assessing quality of reports as described by Jadad et al$^1$ were used; however, the minimum criterion for inclusion in the review was a randomized study. The minimum and maximum scores were therefore 1 and 5, respectively. For studies that compared US against existing methods of nerve location, the quality scores between supportive and negative studies were examined using the Mann-Whitney $U$ test and reported as median (range). Significance was assumed at $P < 0.05$. In addition, a grade of recommendation was assigned based on the number of studies supporting individual outcomes according to the US Agency for Health Care Policy and Research.

RESULTS

A total of 25 randomized studies met the inclusion criteria and are detailed in Tables 1 and 2. Nineteen studies compared US against another nerve location method,$^2$–$^20$ and 6 studies$^2$–$^26$ compared 2 (or more) different US-guided approaches. All studies were randomized studies representing level 1b evidence but varied in study quality (median, 3; range, 1–5).
<table>
<thead>
<tr>
<th>Author (Year)</th>
<th>Jadad Score</th>
<th>Block n</th>
<th>Study Type</th>
<th>Method</th>
<th>LA</th>
<th>Major Findings</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liu et al2 (2009)</td>
<td>3</td>
<td>ISB 21</td>
<td>R</td>
<td>US vs PNS</td>
<td>45–55 mL Mepivacaine 1.5% + epinephrine</td>
<td>Less needle passes (1 vs 2; P &lt; 0.001) and faster motor onset (P = 0.04) in US group</td>
<td>US better</td>
</tr>
<tr>
<td>Morros et al1 (2009)</td>
<td>1</td>
<td>AXB 129 R</td>
<td>US + PNS vs PNS multistimulation</td>
<td>40 mL Mepivacaine 1%</td>
<td>Greater block time in US/PNS group (350 vs 291 secs; P &lt; 0.05); faster onset and less vascular puncture (8% vs 28%; P = 0.01) in US/PNS group</td>
<td>No difference</td>
<td></td>
</tr>
<tr>
<td>Beull et al4 (2009)</td>
<td>5</td>
<td>ICB 103 R, DB</td>
<td>US vs dual end-point PNS</td>
<td>15 mL Bupivacaine 0.5% and 15 mL lidocaine 2%</td>
<td>Greater surgical readiness at 20 mins in US group (85 vs 65%; P = 0.04); faster block performance in US group (5 vs 10.5 mins; P &lt; 0.001)</td>
<td>US better</td>
<td></td>
</tr>
<tr>
<td>Ponde and Diwan (2008)</td>
<td>4</td>
<td>ICB 50 R, DB</td>
<td>US vs PNS</td>
<td>0.5 mL/kg 0.5% Bupivacaine</td>
<td>Greater success in US group (96% vs 64%)</td>
<td>US better</td>
<td></td>
</tr>
<tr>
<td>Taboada et al6 (2008)</td>
<td>3</td>
<td>ICB 35 R, SB</td>
<td>US vs PNS (radial end point)</td>
<td>Mepivacaine 1.5% 0.6 mL/kg 2.5 kg/mL</td>
<td>No difference in block success; fewer needle passes in US group (1 vs 3; P &lt; 0.001)</td>
<td>No difference</td>
<td></td>
</tr>
<tr>
<td>Dhir et al9 (2008)</td>
<td>2</td>
<td>ICB 66 R</td>
<td>Nonstimulating catheter with PNS; stimulating catheter with PNS; US + PNS catheter</td>
<td>Mepivacaine 1.5% 2.5 µg/mL 40 mL</td>
<td>Greater primary (96% vs 58%) and secondary (91% vs 83%; P &lt; 0.001) block success in US group</td>
<td>US better</td>
<td></td>
</tr>
<tr>
<td>Macaire et al10 (2008)</td>
<td>2</td>
<td>Wrist 59 R, SB</td>
<td>PNS vs US for median and ulnar nerve block at wrist</td>
<td>Mepivacaine 1.5% 4 mL each nerve</td>
<td>Faster block onset in PNS group; overall no difference for block performance + onset time</td>
<td>No difference</td>
<td></td>
</tr>
<tr>
<td>Giirkan et al11 (2008)</td>
<td>2</td>
<td>ICB 80 R, SB</td>
<td>US + PNS n = 40 vs PNS n = 40 lateral sagittal ICB (same puncture point)</td>
<td>40-mL Mixture levobupivacaine 0.5% 20 mL + lidocaine 2% 20 mL</td>
<td>Faster block performance in PNS compared with US/PNS group (6.4 vs 7.2 mins; P &lt; 0.05).</td>
<td>PNS better</td>
<td></td>
</tr>
<tr>
<td>Kapral et al12 (2008)</td>
<td>2</td>
<td>ISB 160 R, SB</td>
<td>US vs PNS</td>
<td>Ropivacaine 0.75% 20 mL</td>
<td>Greater surgical anesthesia (99% vs 91%; P &lt; 0.01) and prolonged duration (899 vs 679 mins; P &lt; 0.05) with US</td>
<td>US better</td>
<td></td>
</tr>
<tr>
<td>Yu et al13 (2007)</td>
<td>3</td>
<td>AXB 80 R</td>
<td>US vs PNS</td>
<td>Ropivacaine 0.75% + lidocaine 2%; Total, 32 mL</td>
<td>Faster performance (5.2 vs 14.6 mins; P = 0.000), greater success (100% vs 77.5%; P = 0.005), and less vascular puncture (0 vs 40%; P &lt; 0.001) in US group</td>
<td>US better</td>
<td></td>
</tr>
<tr>
<td>Chan et al14 (2007)</td>
<td>5</td>
<td>AXB 188 R, DB</td>
<td>US, US + PNS</td>
<td>Lidoicaine 2% + bupivacaine 0.5% 5 µg/mL (total 42 mL); 14 mL per nerve</td>
<td>Faster block performance (9.3 vs 11.4 mins; P &lt; 0.01) comparing US vs PNS groups; greater block success in US (82.8%) and US/PNS (80.7%) groups compared with PNS alone (62.9%; P = 0.03)</td>
<td>US better</td>
<td></td>
</tr>
<tr>
<td>Casati et al15 (2007)</td>
<td>3</td>
<td>AXB 60 R, SB</td>
<td>Injection of all 4 nerves by US or PNS</td>
<td>Ropivacaine 0.75% 20 mL</td>
<td>Reduced needle passes (4 vs 8; P = 0.002) and shorter sensory block onset (14 vs 18 mins; P &lt; 0.01) in US group</td>
<td>US better</td>
<td></td>
</tr>
<tr>
<td>Dingemans et al6 (2007)</td>
<td>2</td>
<td>ICB 72 R</td>
<td>US vs US/PNS</td>
<td>Lidoicaine 1.5% + bupivacaine 0.125% + 0.5 mL/kg</td>
<td>Faster performance (3.1 vs 5.2 mins; P = 0.006); greater success in US-alone group (86 vs 57%; P = 0.007)</td>
<td>US alone better</td>
<td></td>
</tr>
<tr>
<td>Sites et al8 (2006)</td>
<td>3</td>
<td>AXB 56 R, SB</td>
<td>US perivascular injection compared with transarterial block</td>
<td>Lidoicaine 1.5% 30 mL</td>
<td>Greater success (100% vs 71%; P &lt; 0.01) and faster performance (7.9 vs 11.1 mins; P &lt; 0.05) in the US group</td>
<td>US better</td>
<td></td>
</tr>
</tbody>
</table>
Studies Comparing US Against Another Nerve Location Technique

Overall, these studies (Table 1) are strongly supportive of the use of US, with 15 studies demonstrating beneficial outcomes including faster block performance, faster block onset, and greater block success. Three studies showed no clear difference, and only 1 study was supportive of the use of peripheral nerve stimulation (PNS) with a faster block performance time in the PNS group. The quality score of positive studies was not different from negative studies (positive: median, 3 [range, 1–5]; negative: median, 2 [range, 1–3]). Eight studies examined infraclavicular block (ICB), 7 studies examined axillary block (AXB), 3 studies examined interscalene block (ISB), 1 study examined supravacular block (SCB), and 1 study examined wrist block.

The 3 studies demonstrating no difference included 1 study examining AXB,1 one examining ICB,11 and another examining wrist block.20 The study that favored PNS involved ICB.11

Studies Comparing Between Different US-Guided Brachial Plexus Blocks

Six studies compared US-guided brachial plexus techniques (Table 2). Four studies compared SCB with ICB block21,23,25; 1 study compared SCB, ICB, and AXB22; and 1 study compared SCB with AXB.26 Two of the studies comparing ICB with SCB found that sparing of the inferior trunk with the SCB led to a higher incidence of block failure in those groups.21,23 Two studies also found a significantly greater incidence of complications21,22 with SCB when compared with both ICB and AXB. One study26 found that the SCB produced better block quality when compared with AXB, although a more recent study found no difference between SCB, ICB, and AXB.25

DISCUSSION

The results of this review suggest that use of US for brachial plexus block provides significant benefits for patients including faster brachial plexus block onset and greater block success. Of the 19 studies comparing US against other nerve location methods, 15 demonstrated significant benefit with US, whereas only 1 study favored PNS (Table 1). Commonly identified benefits of US included surrogates of block performance such as faster block performance time4,6,8,10,13,14,16,18,20 and reduced number of needle passes2,7,15 and surrogates of better quality block including faster sensory onset time4,8,9,12–14,16,20 and greater block success.5,8,9,12–14,16,20 It should be noted, however, that of the 8 studies that found faster block performance with US, 4 studies6,13,16,20 did not include the US scan time required before needle insertion. A fair comparison of block performance time was therefore deemed not to have been made for these studies, and they have been classified as inconclusive (Table 3). However, the highest-quality studies4,14 have demonstrated a clinically and statistically significant reduction in performance time even when scan time was included.

Overall, there were 4 negative studies (3 found no difference,2,7,10 1 favored PNS11), and a number of factors may explain these findings. Early pioneers of US-guided peripheral nerve block techniques hypothesized that the combination of US and PNS would speed block performance time. However, in this review, a number of studies demonstrated that the combination group (US + PNS) had the slowest performance time. Two studies compared a group using PNS with another group using both US and PNS11 and found slower performance time in the US/PNS group. In the study by Chan et al,14 where US was compared against both PNS and combined US/PNS for
<table>
<thead>
<tr>
<th>Author</th>
<th>Jadad Score</th>
<th>Block</th>
<th>n</th>
<th>Study Type</th>
<th>Method</th>
<th>LA</th>
<th>Major Findings</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Koscielniak-Nielsen et al</td>
<td>3</td>
<td>US ICB vs SCB</td>
<td>120</td>
<td>R, SB</td>
<td>US SCB vs ICB</td>
<td>Ropivacaine 0.75% + mepivacaine 2%</td>
<td>Greater success in ICB group (93% vs 78%; <em>P</em> = 0.017) and greater diaphragm paresis in SCB group</td>
<td>ICB better than SCB</td>
</tr>
<tr>
<td>Tran et al22 (2009)</td>
<td>2</td>
<td>US SCB vs ICB</td>
<td>120</td>
<td>R, SB</td>
<td>Perivascular spread technique for all blocks</td>
<td>Lidocaine 1.5% 35 mL</td>
<td>Longer procedure duration in AXB group (8.5 vs 6–6.2 mins; <em>P</em> &lt; 0.008); greater Horner syndrome in SCB group (37.5% vs 0–5%; <em>P</em> &lt; 0.001)</td>
<td>No difference</td>
</tr>
<tr>
<td>Fredrickson et al23 (2009)</td>
<td>4</td>
<td>US SCB vs ICB</td>
<td>60</td>
<td>R, DB</td>
<td>US (no PNS) SCB (corner pocket) vs ICB ( triple-point injection)</td>
<td>Lidocaine 2% 30 mL (weight &lt;65 kg use 25 mL)</td>
<td>Greater surgical anesthesia in ICB compared with SCB (93% vs 67%; <em>P</em> = 0.01) due to ulnar insufficiency</td>
<td>ICB better than SCB</td>
</tr>
<tr>
<td>De Jose Maria et al24 (2008)</td>
<td>2</td>
<td>US SCB vs ICB</td>
<td>80</td>
<td>R</td>
<td>SCB (in plane) vs ICB (out of plane) in children under general anesthesia</td>
<td>Ropivacaine 0.5% up to max 0.5 mL/kg</td>
<td>No proven difference in block success in SCB vs ICB (95% vs 88%; <em>P</em> = 0.39)</td>
<td>No overall difference</td>
</tr>
<tr>
<td>Arcand et al25 (2005)</td>
<td>3</td>
<td>US + PNS for ICB vs SCB</td>
<td>80</td>
<td>R</td>
<td>PNS &lt;0.6 mA and US for all blocks</td>
<td>Bupivacaine 0.5% + lidocaine 2% (1:3 volume); total 0.5 mL/kg; max 40 mL</td>
<td>Greater supplementation required for ICB (18% vs 0%) (<em>P</em> = 0.006) for radial distribution</td>
<td>SCB better than ICB</td>
</tr>
<tr>
<td>Kapral et al26 (1994)</td>
<td>1</td>
<td>US SCB vs AXB</td>
<td>40</td>
<td>RCT</td>
<td>Lateral paravascular SCB approach</td>
<td>Bupivacaine 0.5% 30 mL + 10 mL radiopaque dye</td>
<td>Greater anesthesia in SCB group due to missed musculocutaneous nerve in AXB group</td>
<td>SCB better than AXB</td>
</tr>
</tbody>
</table>

R indicates randomized; DB, double-blind; LA, local anesthetic; SB, single-blind.
TABLE 3. Recommendations for Individual Outcomes Comparing US Against Other Nerve Location Methods for Upper-Extremity Block (Randomized Studies Only)

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Grade of Recommendation</th>
<th>No. Studies Evaluating Outcome (Conclusive/Unclear/Negative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block performance time</td>
<td>I</td>
<td>4/4*/3</td>
</tr>
<tr>
<td>No. needle passes</td>
<td>I</td>
<td>3/0/0</td>
</tr>
<tr>
<td>Vascular puncture</td>
<td>I</td>
<td>2/0/0</td>
</tr>
<tr>
<td>Procedure pain</td>
<td>I</td>
<td>1/0/0</td>
</tr>
<tr>
<td>Sensory onset</td>
<td>A: Supportive for US</td>
<td>6/0/1</td>
</tr>
<tr>
<td>Motor onset</td>
<td>I</td>
<td>1/0/0</td>
</tr>
<tr>
<td>Block success</td>
<td>A: Supportive for US</td>
<td>8/0/0</td>
</tr>
<tr>
<td>Block duration</td>
<td>I</td>
<td>2/0/0</td>
</tr>
</tbody>
</table>

Grades of recommendation: A: good evidence (level I studies with consistent finding) for or against recommending intervention; B: fair evidence (level II or III studies with consistent findings) for or against recommending intervention; C: poor quality evidence (level IV or V studies) for or against recommending intervention; 1: insufficient or conflicting evidence not allowing a recommendation for or against intervention.

*Four studies that were unclear6,13,16,20 demonstrated faster block performance time with US but did not define whether prescan time was included.

†Two of the negative studies compared PNS vs PNS and US. Macaire et al10 demonstrated faster performance time for each nerve, but no difference was found when total block time was evaluated (including scan time).

‡Study by Macaire et al10 in which faster onset time in the PNS group was associated with intraneural injection.

AXB, the combination group had a slower time to perform the block than either the US or PNS group. The reason may be that using both methods for nerve localization may cause operator distraction and prolong performance time. In addition, false-negative responses frequently occur with nerve stimulation where no motor twitch occurs despite apparent proximity of the needle tip to the nerve.27,28 This may be a cause of increased block performance time as the anesthesiologist tries to seek both US and nerve stimulation end points.

Macaire et al10 compared US against PNS for wrist block and found faster block performance time in the US group, but faster block onset time was seen in the PNS group. The authors subsequently demonstrated in several patients that intraneural injection may have been responsible for the faster block onset in the PNS group.

Of the 6 studies that compared US-guided brachial plexus block techniques, 4 compared ICB with SCB.21,23–25 Two of these studies21,23 demonstrated the block success is greater with ICB compared with SCB, and this is mainly related to the increased failure to anesthetize the inferior trunk in the SCB group. In addition, 2 of the 4 studies21,22 found greater block-related complications in the SCB group including Horner syndrome and phrenic block. These results are somewhat surprising given the recent upsurge in the popularity of the US-guided SCB technique related to the purported high block success with a single injection of local anesthetic. However, the position of the inferior trunk immediately above the pleura may explain the difficulty in achieving adequate local anesthetic spread to this area. Further studies and case series are required before definitive conclusions can be drawn regarding the efficacy and adverse effects of the US-guided SCB technique.

Several limitations of this review need to be acknowledged. First, although several of the included studies were performed by experts, in many studies the level of expertise is hard to define. This is especially so for those studies where blocks were performed by both residents and consultant staff. At present, no high-quality randomized studies exist that examine the learning of US by novices alone, and this area needs further investigation. Data regarding complications with US are sparse and significantly limit any conclusions that can be drawn. Adverse outcomes need to be examined by good-quality studies across many more patients than have currently been examined in the relatively small randomized studies discussed here.

Finally, it should be noted that a higher-than-normal number of inconclusive recommendations have been made because we assessed only randomized studies as a minimum requirement for inclusion in this review, and several studies of lower methodological quality do exist but were not included. Had we included these studies, further recommendations may have been possible.

It should be emphasized that US is only one component of the successful and safely performed brachial plexus block and that preexisting basic rules of safe regional anesthesia practice remain very important. These include good training, knowledge of anatomy, and careful technique including slow injection of local anesthetic with regular syringe aspiration and maintenance of verbal contact with the patient.29

In conclusion, this review demonstrates that US-guided brachial plexus block techniques demonstrate several advantages (Table 3) when compared with preexisting nerve location methods including faster onset and greater block success. Future studies should examine use of US in the hands of novices and whether US has any effect on the incidence of serious complications of brachial plexus block.

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Local Anesthetic Volume for Peripheral Nerve Blocks

How Low Can (or Should) We Go?

Colin J.L. McCartney, MBChB, FRCA, FRCPC and Sanjiv Patel, MBBS, FRCA

Peripheral nerve blocks provide significant benefits for our patients, including improved analgesia and reduction in general anesthesia-related adverse effects. However, successful peripheral nerve block requires rapid onset of profound sensory and motor block and adequate duration of action both for the surgical procedure and for provision of postoperative analgesia. In addition, the technique should reduce risk of direct block-related complications and systemic absorption of local anesthetic.

Recent articles in the regional anesthesia literature indicate that ultrasound guidance can shorten procedure time and improve block onset and quality. Several articles have demonstrated that ultrasound-guided techniques can significantly reduce volumes of local anesthetic required to provide successful block compared to other methods, such as peripheral nerve stimulation.

Lower volumes of local anesthetic may be advantageous for several reasons, including limitation of spread to other vital structures like the phrenic nerve when performing interscalene block or reducing the extent of intravascular injection and subsequent systemic complications. Riazi et al recently demonstrated that the use of a low (5 mL) volume of ropivacaine 0.5% for ultrasound-guided interscalene block significantly reduced respiratory impairment compared to a higher-volume (20 mL) technique. Other authors have demonstrated reductions in the required volume of local anesthetic using ultrasound for axillary, femoral, and sciatic blocks. In addition, some studies have shown reduction in adverse systemic events or intravascular injection with the use of ultrasound-guided techniques.

Given the potential advantages of reducing adverse events, it would seem intuitive to attempt to limit the volume of the local anesthetic as much as possible for peripheral nerve block. However, a key question surrounding this practice relates to whether duration will be significantly reduced by reduction in volume. In this issue of Regional Anesthesia and Pain Medicine, Schoenmakers et al compared 15 to 40 mL of mepivacaine 1.5% for ultrasound-guided axillary block (3–4 mL or 10 mL around each of 4 nerves). In a randomized and blinded fashion, the authors compared onset times and duration of anesthesia and sensory block. Their findings indicate first that 2 (13%) of 15 patients in the low-volume group compared to 0 of 15 patients in the high-volume group required rescue block. Second, although sensory and motor block onset time was identical in the remaining patients, in both groups, sensory block duration was significantly shorter in the lower-volume group (225 [148–265] vs 271 [240–401] min; P < 0.001).

Other recent ultrasound studies have also examined this area and found mixed results. O’Donnell et al demonstrated the effectiveness of very low volumes of lidocaine 2% for axillary block and then subsequently demonstrated that the duration of sensory block was reasonable for lidocaine despite the very low volumes (1 mL per nerve) used (mean, 160.8 [30.7] min). In another study, patients given interscalene block for shoulder surgery with 5 mL of ropivacaine 0.5% had similar pain scores up to 24 hours after surgery compared to a larger 20-mL volume. However, other authors have shown that reduced volumes of local anesthetic produce shorter sensory block. Ponrouch et al examined the minimum effective anesthetic volume of mepivacaine 1.5% for median and ulnar nerve blocks and demonstrated a significant correlation between volume and duration despite onset time being unaffected. Fredrickson et al compared a low volume (16 mL), ultrasound-guided ankle block with a conventional technique (30 mL) using ropivacaine 0.5%. Despite greater block success in the lower-volume ultrasound group, pain scores and analgesic consumption were worse in the first 24 hours after surgery.
If local anesthetic is successfully placed around the nerve, why should reduced volume (or dose) shorten duration? According to the pharmacokinetics of local anesthetics, the duration of a block is dependent on the clearance of the drug from the nerve. Larger volumes (given an associated increased total dose) will spread further and contain more local anesthetic molecules. This will lead to a larger depot of local anesthetic molecules stored within fat and muscle surrounding the nerve and also within the myelin surrounding some axons located in the nerve itself, which in turn will lead to block prolongation. The greater volume (and dose) will also maintain the local concentration at a higher level than a lower volume for the first minutes after injection, allowing more effective local anesthetic penetration, which is critical for drug loading, and thus to the subsequent clearance that is the primary determinant of functional recovery. Larger volumes will also spread further and provide greater coverage of nerve for conduction block and thus take longer to recede to the “critical length” where nerve function will resume. Therefore, larger volumes and doses of local anesthetic should increase block duration and, conversely, lower volumes should reduce it. A balance therefore needs to be chosen between increased volume leading to increased spread along the nerve and greater duration, and the consequent risk of excessive spread or incorrect placement that may lead to complications or side effects.

Several questions remain to be answered. If reduced volume of local anesthetic can shorten duration, is this a volume- or dose- (or both) related effect? Although we know that total local anesthetic dose extends the duration of neuraxial techniques, this may not be the case for peripheral nerve blocks. More than 30 years ago, Vester-Andersen et al carried out a novel series of studies examining the effects of varying volume, concentration, and total dose of local anesthetic on perivascular axillary block efficacy. Similar to many subsequent studies, only higher (20–80 mL) volumes of local anesthetic were used, and no measurement of sensory or motor block duration was carried out. More recently, Serradell et al examined the effect of different volumes of mepivacaine 1% (20, 28, and 36 mL) on duration of sensory block and found no difference in duration of analgesia between groups. Possibly, above a certain threshold volume (or dose) there will be minimal difference in duration of sensory block. In addition, it is likely that drugs like ropivacaine, which have some intrinsic vasoconstrictive properties leading to reduced clearance, will have greater duration at lower volumes (and doses) than drugs that have no effect or that vasodilate local blood vessels.

It is likely that large variation in required local anesthetic volume will occur depending on site of block. We have already seen large variations in calculated minimum effective anesthetic volumes depending on block site, and it may make more sense to dose volume of local anesthetic based on nerve or plexus area rather than body weight. The ideal amount of local anesthetic for each site and the balance of volume (and total dose) with duration remains to be determined. Each of these questions will require further study.

In summary, ultrasound-guided techniques have allowed improvements in peripheral nerve block efficacy and reduction in local anesthetic volume for successful block. Recent studies (and pharmacokinetic data) suggest that block duration is reduced at these lower volumes (and doses) of local anesthetic. Further studies are required to determine volume (and dose) of local anesthetic in different locations to determine the ideal balance between onset, efficacy, and duration of peripheral nerve block techniques while reducing adverse effects to the lowest level possible.

ACKNOWLEDGMENT

The authors would like to thank Gary Strichartz, PhD, for his comments on pharmacokinetics of local anesthetic drugs.

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Ultrasound Provides a Reliable Test of Local Anesthetic Spread

Colin J. L. McCartney, MBChB, FRCA, FCARCSI, FRCP, * Victoria Dickinson, BA, * Adam Dubrowski, PhD, † Sheila Riazi, MD, FRCP, * Paul McHardy, MD, FRCP, * and Imad T. Awad, MD, FCARCSI *

Background and Objectives: We predicted that practitioners could identify injectate spread in a model of ultrasound-guided peripheral nerve block.

Methods: Both novices and experts in ultrasound-guided peripheral nerve block were asked to recognize the spread of local anesthetic in a gelatin ultrasound phantom. In a blinded and randomized fashion, these participants were observed to either successfully or unsuccessfully state whether an injection had been made.

Results: Twelve novices and 8 experts each completed the trials. Accuracy, Sensitivity and specificity were calculated for all trials. Participants attained a very high accuracy and sensitivity (>85%) as well as specificity (>90%) with ultrasound in this model.

Conclusions: This study shows that ultrasound is a reliable method of detecting injectate spread in a gelatin phantom model.

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Peripheral nerve block techniques provide many advantages for patients, including decreased pain, reduction in nausea and vomiting, and faster discharge from hospital after surgery. The use of ultrasound has been demonstrated in a number of recent studies to provide advantages with regard to onset time, block efficacy, and block performance time. One of the advantages of ultrasound-guided techniques is the ability to recognize local anesthetic spread as it is injected around a target structure. This provides a number of potential advantages including visual confirmation of correct local anesthetic spread and ability to reduce local anesthetic volume. Conversely, lack of visual spread on injection can indicate either poor visualization of the needle tip or misplacement in unintended areas such as blood vessels. The ability to quickly recognize correct spread or lack thereof of small volumes of injectate could enable both improved efficacy and possible safety of peripheral nerve blocks.

We decided to test using a bench-top model whether users of ultrasound could accurately identify tissue spread of small volumes of local anesthetic. Our hypothesis was that practitioners would be able to recognize tissue placement with ultrasound after injection of 1 mL of local anesthetic in a simple model of ultrasound-guided peripheral nerve block placement.

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METHODS

The study was approved by the Research Ethics Board of Sunnybrook Health Sciences Centre. Trainee (resident and fellows) and staff anesthesiologists in the Department of Anesthesia at the University of Toronto were asked to volunteer their time and participate in this study and gave written informed consent to be involved.

Twelve novices (<10 ultrasound-guided blocks) and 8 experts (>50 ultrasound-guided blocks) were asked to attempt the recognition of injectate spread in an ultrasound phantom (Fig. 1). In total, there were 20 participants and 32 trials per participant for 640 trials in total. The phantom used for the task was gelatin based and individually prepared for each participant. Food coloring was added to the model to render the phantom semiopaque, and raisins were embedded in between layers of the model to act as target structures. A number of other options were considered for use in this experiment (eg, a commercially available phantom, animal tissue, etc), but the gelatin-based model had both cost and practical advantages, as well as being of reasonable fidelity.

Participants were instructed to place an insulated 22-gauge nerve block needle (B. Braun Medical Inc, Bethlehem, Pa) in a phantom model of a nerve block at a superficial (<2 cm) depth with an ultrasound machine using the in-plane technique (SonoSite Micromaxx with a 10- to 13-MHz linear ultrasound probe; SonoSite Inc, Bothell, Wash).

Three practice attempts were made at placing the needle tip next to the target before performing the following series of tests. Under ultrasound guidance, a 22-gauge needle was placed in the phantom by the participant, and a target structure approached. Once the participant had succeeded in placing the needle tip adjacent to the target, he/she indicated to the research associate to inject. In a blinded fashion (the participant did not know whether injection had occurred or not), the research associate either injected 1 mL water (simulated local anesthetic injection in tissue) or made no injection. After each test, the candidate confirmed whether injection had been made before removing the ultrasound probe and needle and beginning the next test. The order of either simulated tissue injection or no injection followed a stratified randomization protocol with groups of 8 trials; that is, within every group of 8 trials, there were 4 of each either injection or no injection in a randomized fashion. Eight trials per participant per each of the 4 conditions were selected to ensure that all participants reached a stable performance in this new environment.

Previous research demonstrates that even for experienced practitioners learning effects are present when performing in simulated setting and that 2 trials for an advanced practitioner and a 6- to 8-trial period for a novice are necessary to alleviate these transient effects. The randomization was achieved using a random-number generator for each participant.

Data were collected on the number of correct and incorrect responses and the time to respond for each trial (defined as the time from injection by the research associate to the response by the operator).
Statistical Analysis

Statistical analysis was performed using SPSS statistical software (version 16.0; SPSS Inc, Chicago, Ill) and Microsoft Excel where appropriate. Significance was assumed at $P \leq 0.05$. Observers categorized each trial as “injection made” or “injection not made.”

Accuracy, sensitivity, specificity, positive predictive value, and negative predictive value were calculated for novices and experts. To check for improvements in discriminatory ability (ie, learning due to practice), the proportion of responses falling into each category was compared between the first 16 and the last 16 trials of the sessions using a Pearson $\chi^2$ test. If learning had occurred, the proportion of correct responses would be significantly higher for the last 16 trials. To further analyze for evidence of learning, a $t$ test was performed to compare the mean time to response for the first 16 and last 16 trials, and between experts and novices. In addition, both a $\chi^2$ test and a 2-proportion $z$ test were performed to determine if novices and experts showed a different pattern of errors in the task, and the accuracy, sensitivity, and specificity values for each group were compared.

RESULTS

The response data from the trials in the ultrasound model are shown in Table 1. A total of 12 novices and 8 experts performed 32 trials. Two participants were not able to complete a full 32 trials; one of these participants completed 16 trials, and the other completed 24 trials. Accuracy, sensitivity, specificity, and positive and negative predictive value data are displayed in Table 2. The accuracy of the test was always greater than 90%. The sensitivity of ultrasound ranged from 85% in novices in the model to 92% in experts. Experts performing the test in the model achieved a sensitivity that was significantly greater than that of the novices ($P<0.05$). Experts also achieved a significantly greater negative predictive value than did novices in the model ($P<0.05$). The specificity of the test was around 95% in all cases, with no significant differences between novices and experts.

There was no significant difference in the pattern of response types between the first and last 16 trials ($P=0.447$). However, the mean time to respond was significantly less during the last 16 trials (3.17 vs 3.90 sec; $P<0.001$). There was no significant difference in the mean time to respond between experts and novices ($P=0.55$).

TABLE 1. Summary of Test Evaluation Statistics

<table>
<thead>
<tr>
<th></th>
<th>Novices</th>
<th>Experts</th>
<th>$P^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>0.911 (0.882–0.926)</td>
<td>0.930 (0.892–0.955)</td>
<td>NS</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>0.850 (0.821–0.865)</td>
<td>0.922 (0.885–0.947)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Specificity</td>
<td>0.972 (0.943–0.988)</td>
<td>0.937 (0.899–0.962)</td>
<td>NS</td>
</tr>
<tr>
<td>PPV</td>
<td>0.968 (0.935–0.986)</td>
<td>0.937 (0.899–0.962)</td>
<td>NS</td>
</tr>
<tr>
<td>NPV</td>
<td>0.866 (0.841–0.880)</td>
<td>0.922 (0.885–0.947)</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

Numbers in brackets are 95% confidence intervals.

*Novices and experts were compared using a 2-proportion $z$ test and confidence intervals were further derived from those data.

NS indicates not statistically significant; PPV, positive predictive value; NPV indicates negative predictive value.

DISCUSSION

The present study demonstrates that ultrasound is a reliable method of detecting small volumes of injectate during a superficial nerve block in a low-fidelity model when used by both novices and experts.

Users attained a very high (>90%) accuracy and specificity with ultrasound. Sensitivity was only marginally lower. It is especially important that this test has a high specificity, given that false positives (perceived injectate spread where none had actually occurred) may represent poor visualization of needle tip or lack of awareness that unintentional injection in other unwanted areas such as blood vessels was occurring. In this study, all users showed an impressively high specificity when using ultrasound.

This study did not demonstrate substantial learning benefit across the 32 trials on the low-fidelity model in that there was no difference in the proportion of errors between the first 16 and last 16 trials. It is possible that the 3 “practice” trials that participants were allowed before starting the task were sufficient training to allow participants to reliably differentiate between presence and absence of injectate. There was a small but significant decrease in response time between the first and last 16 trials, and this may be a reflection of improved speed and accuracy with regard to correct visualization of needle tip and presence or absence of injectate. In this model, minimal teaching (3 trial attempts) seemed to be satisfactory to obtain the benefits of using ultrasound to recognize tissue spread of injectate, although smaller gains in speed and accuracy were made with much greater experience. This is in line with previous reports in other domains of simulation-based clinical skills training.

A future study might investigate this same task in those with no prior experience with ultrasound or peripheral nerve blocks and deny participants the opportunity for practice trials, to better document the learning trajectory of this skill.

Despite the lack of overt difference between novices and experts on our task, there did seem to be some more subtle
differences between the groups. For instance, novices seemed to be more likely than experts to make false-negative errors, although this result was not statistically significant. Novices, however, did have a significantly lower sensitivity on this task than did experts. Perhaps novices are less skillful at visualizing the needle tip and seeing injection spread or require more evidence to respond that injection has actually occurred. In practice, this would mean that novices performing ultrasound-guided peripheral nerve blocks might be more likely to pause and search for other evidence of injectate spread, something that might slow block performance.

This model may also prove to be a useful training tool for novice anesthesiologists before attempting ultrasound-guided regional anesthesia in patients. Results from the technical skills literature also suggest that hands-on training will improve the performance of a skill, no matter the fidelity of the model.16

The results of this study strongly suggest that ultrasound is useful for successfully identifying correct tissue placement of local anesthetic during peripheral nerve blocks. Conversely, a correctly identified lack of injectate spread is often seen when unintentional intravascular injection takes place, and the high specificity in this study may indicate that ultrasound can additionally provide an early sign of intravascular needle placement. If true, this would allow practitioners to remove and redirect their needle before further injection and potentially reduce the chance of significant intravascular doses of local anesthetic.

We did not perform sample size estimation before commencing this study because of lack of available data to estimate variability of the measures performed. However, our comparative data demonstrate impressive levels of sensitivity and specificity for this model. In addition, our results demonstrate significant findings with regard to differences between novices and experts with regard to sensitivity and negative predictive value. It is possible, however, that we have a type II error with our lack of ability to find differences between novices and experts for specificity and positive predictive value, and these findings should be interpreted with caution until further data are available.

In summary, the data from this study suggest that ultrasound is a useful tool to facilitate correct placement of local anesthetic around superficial target structures when used both by novices and experts. In addition, the data from this study suggest that using ultrasound to observe correct spread may be helpful in avoiding large intravascular injections of local anesthetic in a gelatin phantom model.

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REFERENCES

Effect of local anaesthetic volume (20 vs 5 ml) on the efficacy and respiratory consequences of ultrasound-guided interscalene brachial plexus block

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Background. Interscalene brachial plexus block (ISBPB) is an effective nerve block for shoulder surgery. However, a 100% incidence of phrenic nerve palsy limits the application of ISBPB for patients with limited pulmonary reserve. We examined the incidence of phrenic nerve palsy with a low-volume ISBPB compared with a standard-volume technique both guided by ultrasound.

Methods. Forty patients undergoing shoulder surgery were randomized to receive an ultrasound-guided ISBPB of either 5 or 20 ml ropivacaine 0.5%. General anaesthesia was standardized. Both groups were assessed for respiratory function by sonographic diaphragmatic assessment and spirometry before and after receiving ISBPB, and after surgery. Motor and sensory block, pain, sleep quality, and analgesic consumption were additional outcomes. Statistical comparison of continuous variables was analysed using one-way analysis of variance and Student’s t-test. Non-continuous variables were analysed using χ² tests. Statistical significance was assumed at P<0.05.

Results. The incidence of diaphragmatic paralysis was significantly lower in the low-volume group compared with the standard-volume group (45% vs 100%). Reduction in forced expiratory volume in 1 s, forced vital capacity, and peak expiratory flow at 30 min after the block was also significantly less in the low-volume group. In addition, there was a significantly greater decrease in postoperative oxygen saturation in the standard-volume group (−5.85 vs −1.50, P=0.004) after surgery. There were no significant differences in pain scores, sleep quality, and total morphine consumption up to 24 h after surgery.

Conclusions. The use of low-volume ultrasound-guided ISBPB is associated with fewer respiratory and other complications with no change in postoperative analgesia compared with the standard-volume technique.

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Keywords: anaesthetic techniques, regional, brachial plexus; analgesics, postoperative; complications, respiratory

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Interscalene brachial plexus block (ISBPB) is one of the most reliable and commonly performed techniques for regional anaesthesia of the upper extremity. It anaesthetizes the caudal portion of the cervical plexus (C3, C4) and the superior (C5, C6) and middle (C7) trunks of the brachial plexus. ISBPB is associated with a number of complications,¹ but the most common is phrenic nerve palsy, which occurs in 100% of patients using current techniques.² The phrenic nerve arises chiefly from the C4 root, with variable contributions from C3 and C5. It is formed at the upper lateral border of the anterior scalene muscle and courses caudally between the ventral surface...
of the anterior scalene muscle and prevertebral fascial layer that covers this muscle, therefore separated from the brachial plexus only by a thin fascial layer. As a result, its block in ISBPB can be explained by the proximity to the brachial plexus or to the cephalad spread of local anaesthetic to the C3–5 roots of the cervical plexus before their formation of the phrenic nerve.

Phrenic nerve block is associated with significant reductions in ventilatory function including a 21–34% decrease in forced vital capacity (FVC), 17–37% decrease in forced expiratory volume in 1 s (FEV₁), and 15.4% decrease in peak expiratory flow rate (PEFR). Therefore, ventilation can be compromised by ISBPB which restricts the use of this block in patients with limited pulmonary reserve such as those with chronic obstructive pulmonary disease (COPD), the morbidly obese, or the elderly.

Previous efforts to determine the minimum effective local anaesthetic dose for ISBPB with the least decrease in hemidiaphragmatic paresis occurred in 80% of subjects who received bupivacaine 0.5% (10 ml) and only in 17% of those who received bupivacaine 0.25%. Ultrasoundography (US) can be used to identify brachial plexus anatomy, guide needle placement, and visualize local anaesthetic spread. This technique may improve correct placement of local anesthetic and minimize complications because individual nerves can be more effectively located and lower volumes of local anaesthetic directed around the target structure. In turn, this may decrease the unintentional spread of local anaesthetic to the phrenic nerve. In this study, we hypothesized that by reducing local anaesthetic volume during ultrasound-guided interscalene block, it is possible to reduce the incidence, severity, or both of phrenic nerve block without sacrificing quality or duration of analgesia after shoulder surgery.

Methods

After institutional research ethics board approval and written informed consent, 40 patients undergoing right-sided shoulder surgery were recruited to this double-blind, randomized controlled trial. Inclusion criteria were age ≥18 and ≤80 yr, ASA I–III, and BMI <35. Exclusion criteria included pre-existing COPD, unstable asthma, psychiatric history, renal or hepatic impairment, allergy to ropivacaine, and opioid tolerance (>30 mg oral morphine or equivalent per day).

Patients were randomized using a computer-generated randomization sequence and using sealed, opaque envelopes to two groups, receiving an ultrasound-guided posterior approach ISBPB of either 5 or 20 ml of ropivacaine 0.5%. The patients and research assistant assessing the block success and diaphragmatic function were blinded to the treatment allocation.

After applying routine monitors including electrocardiography (ECG), non-invasive arterial pressure, and pulse oximetry, i.v. access was established in the contralateral arm, with an infusion of saline 0.9% at a maintenance rate. Patients were given oxygen 6 litre min⁻¹ via facemask, i.v. midazolam 0.03 mg kg⁻¹ for sedation, oral celecoxib 400 mg, and oral acetaminophen 1000 mg as part of the standardized care for shoulder surgery patients.

Patients were positioned in the left semilateral position with the neck extended to facilitate performance of US ISBPB (Fig. 1). After sterile skin preparation with chlorhexidine and skin infiltration with lidocaine 1%, US ISBPB was performed. A 5 cm 22 G insulated needle (B. Braun Medical Inc., Bethlehem, PA, USA) was inserted in-line with the ultrasound probe in the transverse plane (Fig. 1). An Advanced Technology Lab (ATL) 2–13 MHz probe was used to visualize the brachial plexus (Fig. 2) using a Philips HD11 XE ultrasound machine (Philips Medical Systems, Bothell, WA, USA). The two outermost nerve roots (C5 and C6) between the anterior and the middle scalene muscles were further confirmed by identification with nerve stimulation (frequency 2 Hz, pulse width 0.1 ms, and increasing current from 0.1 to 1 mA or until motor stimulation of the deltoid or biceps muscle was noted) (Portex Tracer III, Keene, NH, USA). The local anaesthetic was then injected, so that spread was seen immediately posterior to or between the C5 and the C6 nerve roots.

After the performance of ISBPB and initial assessment, patients were taken to the operating theatre where they were given a general anaesthetic using a standardized protocol, consisting of propofol 2–2.5 mg kg⁻¹ and fentanyl 1 μg kg⁻¹. Rocuronium 0.6–0.8 mg kg⁻¹ was used for patients requiring endotracheal intubation. The airway was maintained either with a laryngeal mask airway or tracheal tube and the lungs were ventilated with oxygen–nitrous oxide.
Interscalene block and volume

Fig 2 Sonogram of the interscalene area at the C7 level. The needle approach is from the lateral aspect through the middle scalene muscle (ASM, anterior scalene muscle; MSM, middle scalene muscle; C5, C5 nerve root; C6, C6 nerve root). At this level, the C5 and C6 roots can commonly be seen to join to form the superior trunk of brachial plexus.

Diaphragmatic excursion was assessed by real-time US of the ipsilateral hemidiaphragm at the cephalad border of the zone of apposition (Zap) of the diaphragm to the costal margin between the midclavicular and the anterior axillary lines. An ATL 2–5 MHz curvilinear probe was used to visualize the diaphragm using a Philips HD11 XE ultrasound machine (Philips Medical Systems). All assessments were performed with the patient in the supine position during quiet inspiration, deep inspiration, and forceful sniff. Diaphragmatic movement was assessed both in B mode and in M mode settings. Normal inspiratory caudad diaphragmatic excursion is designated as positive (+) motion, and paradoxical cephalad motion as negative (−) motion. Each test was performed three times. Bedside spirometry using a compact spirometer (Spirolab III, Medical International Research) was performed with patients lying in a 45° semi-recumbent position, and after instruction on how to perform the test, FVC, FEV1, and PEFR measurements were performed three times and the values were averaged. Sensation of the upper extremity was assessed by pinprick using a 23 G needle testing from C4 to T1 dermatomes and scored as full sensation=1 and loss of sensation to touch or pinprick=0. Motor power assessment of the deltoid, biceps, triceps, finger flexion (median), finger extension (radial), and finger abduction (ulnar) was scored as movement present=1 and no movement present=0. All of the above assessments (diaphragmatic excursion, spirometry, sensory, and motor assessment) were done at baseline (pre-block), 10, 20, and 30 min post-block, and 30, 60, 120, and 180 min after completion of surgery.

Patients were instructed to rate their pain using an 11-point verbal rating scale (VRS) ranging from 0 to 10 (0, no pain; 10, worst imaginable pain). VRS was measured at 30, 60, 120, and 180 min, at 22:00 on the evening of surgery and 24 h after surgery. Quality of sleep on the first postoperative night was also measured and assessed by difficulty sleeping (yes/no) and wake-up frequency. Patients in recovery room were allowed i.v. morphine 2–5 mg for pain or 1–2 tablets of a compound preparation of codeine 30 mg and acetaminophen 500 mg or oxycodone 5 mg and acetaminophen 500 mg. After discharge from recovery room, patients were allowed 1–2 tablets of a compound preparation of codeine 30 mg and acetaminophen 500 mg or oxycodone 5 mg and acetaminophen 500 mg every 4 h for pain if required. All opioid doses for total dose in recovery room and total dose in the first 24 h after discharge from recovery room were converted to oral morphine equivalents for ease of analysis. Analgesia was given on patient request or if VAS >3 (moderate–severe pain). Patients who were discharged the same day (37 patients) were given a diary to complete and were also contacted at home 24 h later to complete pain, analgesic consumption, sleep, and satisfaction data.

The primary outcome measure was diaphragmatic movement 30 min after ISBPB. Secondary outcomes included spirometric measures, motor/sensory block onset and duration, VRS for pain, other side-effects including Horner’s syndrome, hoarseness, analgesic-related adverse effects, patient satisfaction with analgesia, and sleep quality on the first postoperative night.

Statistical comparison of baseline ipsilateral hemidiaphragmatic excursion with post-block excursion was tested using a χ² test. Baseline spirometric values with measures post-ISBPB were tested using one-way analysis of variance (ANOVA) and further defined using Student’s t-test. VRS and other continuous variables were also analysed using non-parametric ANOVA and Mann–Whitney U-test. Other non-continuous variables were analysed using χ² tests.

The study sample size was estimated assuming a reduction in decrease of spirometric values using the proposed low-volume US ISBPB technique. Estimates from Al-Kaisy and colleagues demonstrated a reduction in decrease of FVC from 74.6% of normal to 86.6% of normal with reduction in dose from bupivacaine 0.5% (10 cc) to bupivacaine 0.25% (10 cc). We estimated a similar or larger reduction in diaphragmatic dysfunction with our lower dose of ropivacaine 0.5% (5 ml). In order to determine a reduction from normal in diaphragmatic...
dysfunction as measured by FVC from 75% to 87% with 
\( \alpha = 0.05 \) and \( \beta = 0.8 \), we estimated that we required 19 patients per group.

Results

Between July and December 2007, 40 patients were ran-
domized to Group 1 (n=20, low volume) or Group 2 (n=20, standard volume). The flow diagram of patients approached, consented, and recruited is shown in Figure 3. There were no differences in patient characteristics between Group 1 and Group 2 (Table 1).

Baseline diaphragmatic movement was similar and normal in all patients. Thirty minutes after ISBPB, paradoxical (negative) diaphragmatic movement was seen in all (100%) of the standard-volume group and 45% of the low-volume group (P<0.05). There was a significant reduction in lung volumes (FVC, FEV1, and PEF) at 30 min post-ISBPB in the standard-volume group when compared with the low-volume group (−1.59 vs −0.70 litre; −1.23 vs −0.60 litre; −2.50 vs −0.83 litre min\(^{-1}\)). Post-operative oxygen saturation decrease was also significantly greater (−5.85% vs −1.5%) in the standard-volume group (Table 2). One patient in the standard-volume group developed respiratory distress after ISBPB, with a decrease in oxygen saturation to 80% requiring high flow oxygen (50%) via Hudson mask. This patient was not able to perform bedside spirometric measurements after ISBPB.

Pain score (VRS) measured at 30, 60, 120 min, 12, and 24 h after surgery and also total morphine-equivalent consumption in the recovery room and in the first 24 h after surgery were similar in both groups. Sleep quality, wake-up frequency because of pain, and satisfaction scores were all similar in both groups (Table 3). One patient in the low-volume group required a supplementary superficial cervical plexus block after surgery for severe (VRS 10) pain in an incision in the C4 distribution. The postoperative analgesic data in this patient were excluded from further analysis after the rescue block. The patient had a VRS of 0 after the rescue block, which would have biased the pain scores in the low-volume group.

Sensory and motor block onset and extent of block is depicted in Figures 4 and 5. There was a significantly slower onset of loss of pinprick sensation in the C4 distribution in the low-volume group, but no other differences in sensory onset. Patients in the standard-volume group had significantly greater loss of pinprick sensation in C4 and C5 distribution at 30 and 60 min after surgery. In the standard-volume group, there was significantly faster onset of motor block in biceps and triceps. After surgery, significantly more patients in the standard-volume group experienced motor block of biceps, triceps, and median nerve function (finger flexion).

Eight patients in the standard-volume and no patients in the low-volume group developed post-block complications. In the standard-volume group, one patient suffered hypoxia and respiratory distress, three patients developed ipsilateral Horner’s syndrome, three patients developed post-block hoarseness, and one patient developed hiccups lasting for 3 days.

Discussion

The results of this study demonstrate that administration of a low-volume ISBPB under ultrasound guidance decreases the incidence of hemidiaphragmatic paresis and preserves respiratory function while providing equivalent analgesia when compared with a standard-volume ultrasound-guided technique. In addition, other adverse effects related to interscalene block such as Horner’s syndrome and voice hoarseness only developed in the standard-volume group. Therefore, a low-volume of local anaesthetic administered under ultrasound guidance can improve the overall safety without any decrease in the efficacy of ISBPB.

Ultrasound-guided nerve blocks allow direct visualization of target nerves, adjacent anatomical structures, and needle position. As a result, the spread of local anaesthetic around target nerves can be assessed and more precisely administered at the correct location. In this study, ultrasound allowed us to visualize the brachial plexus at the
interscalene groove (lateral approach; needle insertion through the middle scalene) and administer a lower volume of local anaesthetic at the C5 and C6 nerve roots. This resulted in a lower incidence of phrenic nerve palsy (45% at 30 min post-block) and better preservation of respiratory function in terms of greater FEV\textsubscript{1}, FVC, PEF, and oxygen saturation compared with the standard-volume group. Furthermore, analgesia was similar between the two groups indicating that ropivacaine 0.5% (5 ml) can spread sufficiently to anaesthetize the shoulder while sparing the phrenic nerve. Therefore, these findings provide evidence in support of the use of low-volume local anaesthetic for ISBPB for shoulder surgery.

Avoidance of diaphragmatic dysfunction after ISBPB is of benefit to all patients undergoing shoulder surgery, especially those with obesity or respiratory disease. Obese patients are predisposed to osteoarthritis and therefore may especially those with obesity or respiratory disease. Obese ISBPB for shoulder surgery.

Therefore, these findings provide evidence in support of the use of low-volume local anaesthetic for ISBPB for shoulder surgery.

Although one patient in the low-volume group in this study required rescue analgesia, this was because the incision site was in the C4 distribution, which is outside the normal distribution of sensation for the shoulder joint (C5/6). Our recommendation is that if the surgeon intends to place an incision in the C4 area, then a superficial cervical plexus block should be performed in addition to an ISBPB. More easily, the surgeon could infiltrate the surgical incision site with local anaesthetic, preferably before incision.

This is the first randomized controlled trial demonstrating that a lower volume of local anaesthetic in an ultrasound-guided ISBPB is associated with improved respiratory function while providing effective analgesia compared with a standard-volume technique. We found that 100% of patients receiving standard volumes of local anaesthetic for ISBPB experienced hemidiaphragmatic paresis and reduced lung function. In this study, the decrease in respiratory function led to a significantly greater reduction in oxygen saturation ($S_{Po_2}$) in the high-volume group. This finding is consistent with a previous study that also found 100% hemidiaphragmatic paresis and a 25% reduction in FVC and FEV\textsubscript{1} using meptivacaine 1.5% (34–52 ml) for ISBPB. Although our findings indicate that the incidence of hemidiaphragmatic paresis was

### Table 2 Respiratory function and adverse outcomes post-ISBPB

<table>
<thead>
<tr>
<th>Group I: low volume, mean (sd)</th>
<th>Group II: standard volume, mean (sd)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paralysed diaphragm at 30 min post-block 9/20</td>
<td>20/20</td>
<td>$P&lt;0.05$</td>
</tr>
<tr>
<td>Paralysed diaphragm at 60 min post-surgery 6/18</td>
<td>18/20</td>
<td>$P&lt;0.05$</td>
</tr>
<tr>
<td>Change in FVC at 30 min post-block (litre) $-0.70 (0.70)$</td>
<td>$-1.59 (0.68)$</td>
<td>$P&lt;0.05$</td>
</tr>
<tr>
<td>Change in FEV\textsubscript{1} at 30 min post-block (litre) $-0.60 (0.54)$</td>
<td>$-1.23 (0.61)$</td>
<td>$P&lt;0.05$</td>
</tr>
<tr>
<td>Change in PEF at 30 min post-block (litre min\textsuperscript{-1}) $-0.83 (1.01)$</td>
<td>$-2.50 (1.61)$</td>
<td>$P&lt;0.05$</td>
</tr>
<tr>
<td>Oxygen saturation pre-block (%) 97.3 (0.92)</td>
<td>97.5 (1.58)</td>
<td>$P=0.3$</td>
</tr>
<tr>
<td>Oxygen saturation 30 min post-surgery (%) on air 95.8</td>
<td>91.7</td>
<td>$P=0.003$</td>
</tr>
<tr>
<td>Change in oxygen saturation $-1.50 (3.13)$</td>
<td>$-5.85 (3.78)$</td>
<td>$P=0.0001$</td>
</tr>
<tr>
<td>Adverse outcomes 0</td>
<td>8 (Horner’s syndrome: 3, hoarseness: 3, severe respiratory distress: 1, hiccups: 1)</td>
<td>$P&lt;0.05$</td>
</tr>
</tbody>
</table>

### Table 3 Pain scores, analgesic consumption, sleep quality, and satisfaction. Pain scores were from 0 to 10 (0, no pain), satisfaction scores were from 0 to 10 (0, not satisfied). *Including patient with pain in the C4 distribution (VAS10) requiring rescue superficial cervical plexus block. † Including patient who required rescue superficial cervical plexus block.

<table>
<thead>
<tr>
<th>Group I: low volume</th>
<th>Group II: standard volume</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pain score 30 min post-surgery, mean (sd)\textsuperscript{a} 1.1 (2.8) range: 0–10</td>
<td>0.3 (1.4) range: 0–6</td>
<td>NS</td>
</tr>
<tr>
<td>Pain score 60 min post-surgery, mean (sd) 1.1 (2) range: 0–6</td>
<td>1 (2.1) range: 0–6</td>
<td>NS</td>
</tr>
<tr>
<td>Pain score 120 min post-surgery 0.5 (1.1)</td>
<td>1.3 (2.2)</td>
<td>NS</td>
</tr>
<tr>
<td>Pain score 12 h post-surgery 3.4 (2.8) range: 0–8</td>
<td>3.1 (2.53) range: 0–6</td>
<td>NS</td>
</tr>
<tr>
<td>Pain score 24 h post-surgery 3.6 (2.3) range: 0–7</td>
<td>4.7 (2.9) range: 0–10</td>
<td>NS</td>
</tr>
<tr>
<td>Difficulty sleeping 7/20</td>
<td>10/20</td>
<td>NS</td>
</tr>
<tr>
<td>Wake-up frequency, mean (sd) 0.8 (1.4)</td>
<td>1.7 (1.9)</td>
<td>NS</td>
</tr>
<tr>
<td>Satisfaction score, mean (sd) 8.5 (1.6)</td>
<td>7.1 (2.9)</td>
<td>NS</td>
</tr>
<tr>
<td>Intraoperative fentanyl (µg) 140.3 (40.3)</td>
<td>107.5 (61.3)</td>
<td>NS</td>
</tr>
<tr>
<td>Total morphine (oral) equivalent consumption in recovery room (mg), mean (sd) 2.9 (6.9)</td>
<td>1.3 (4.6)</td>
<td>NS</td>
</tr>
<tr>
<td>Number of patients requiring analgesics in recovery room\textsuperscript{b} 5</td>
<td>3</td>
<td>NS</td>
</tr>
<tr>
<td>Total morphine equivalent consumption (oral) in first 24 h after surgery (after discharge from recovery room) (mg), mean (sd) 23.3 (17.4)</td>
<td>26.5 (13.6)</td>
<td>NS</td>
</tr>
</tbody>
</table>
significantly lower with ropivacaine (5 ml), it nevertheless can still occur. We found that 45% (9 out of 20) of the low-volume group still experienced phrenic nerve palsy 30 min after block completion.

This study adds to the data of Al-Kaisy and colleagues who documented a reduction in respiratory dysfunction in a volunteer population randomized to either 10 ml of 0.5% or 0.25% bupivacaine. Our results are distinguished by using a lower volume of local anaesthetic (aided by a precise ultrasound-guided technique) and also, in contrast to Al-Kaisy and colleagues, we have demonstrated these benefits in a population undergoing painful shoulder surgery. A further demonstrated benefit of the low-volume technique is a significant reduction in motor block in the forearm and hand after surgery. In our study, patients in the low-volume group had significantly increased power in biceps, triceps, and finger flexion after surgery. Although patients appreciate the profound analgesia from standard interscalene techniques, many also complain about the prolonged motor block after surgery. Though our differences in patient satisfaction did not reach statistical significance, the trend towards greater satisfaction (mean 8.5 vs 7.1) in the low-volume group may have reflected the reduction in motor block. It is also interesting to note that despite the lack of difference in pain scores or analgesic consumption between the groups that patients in the standard-volume group had significantly reduced sensation to pinprick in the C4 and C5 distribution after surgery and that if anything these patients should have experienced less pain after surgery.

This study has a number of limitations. First, it should be noted that without ultrasound, we do not know if a 5 ml volume of local anaesthetic is sufficient for interscalene block. The ultrasound approach allowed for a precise deposition of local anaesthetic around the C5/6 nerve roots and the posterior approach through the middle scalene muscle may help to prevent anterior spread to the phrenic nerve. Secondly, although the incidence and duration of phrenic paresis can be reduced with a low-volume ultrasound-guided technique, it cannot be avoided entirely; therefore,
caution should be used, especially if a patient has a con-
tralateral pre-existing phrenic paresis. Some of our respira-
tory parameters may have been influenced both by the
sedation administered before ISBPB placement and by the
effect of recovery from general anaesthesia, including
residual neuromuscular block after surgery. However,
although 35 of 40 patients received rocuronium for endo-
tracheal intubation, in this study, there were more patients
with tracheal intubation in the low-volume group (19
vs 16) compared with the high-volume group. If anything,
therefore, there would have been more tendency towards
residual curarization in the low-volume group, even though no clini-
cal evidence was seen of any skeletal muscle weakness
(other than in the blocked arm) in any patient.

Finally, although the study randomization was blinded,
both to patients and to assessor, the anaesthetist perform-
ing the block was not blinded to volume injected and this
could arguably have influenced needle placement during
the block. However, this effect, if anything, should favour
the standard (20 ml) volume group because there would
have been much more opportunity in this group to correct
any perceived maldistribution of local anaesthetic spread
by moving the needle tip during the block.

In conclusion, this study found that the use of a low-
volume ultrasound-guided ISBPB is associated with a lower
incidence of phrenic nerve palsy and other block-related
complications while maintaining effective analgesia com-
pared with a standard-volume technique. This technique
may allow patients at higher risk of postoperative respira-
tory complications to undergo ISBPB for shoulder surgery
and benefit from the profound analgesia that it can provide
with a significantly decreased risk of respiratory
complications.

Funding
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Canada.

![Fig 5](http://bja.oxfordjournals.org/atSunnybrookHealthSciencesCentreOnMay10,2013)

Fig 5 Number of patients with preservation of movement in each muscle group. D, deltoid; B, biceps; T, triceps; M, finger flexion (median); R, finger
extension (radial); U, finger abduction (ulnar). B, baseline; 10PB, 10 min post-block; 20PB, 20 min post-block; 30PB, 30 min post-block; 30PS,
30 min post-surgery; 60PS, 60 min post-surgery. *Significant difference in ability to move between the groups.
References
Ultrasound reduces the minimum effective local anaesthetic volume compared with peripheral nerve stimulation for interscalene block

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Key points
- Comparison of ultrasound (US) guided and nerve stimulation (NS) for interscalene block.
- Sequential up–down dosing was used to evaluate the minimum effective analgesic volumes.
- All patients received general anaesthesia with opioid and were followed up for 3 h after operation.
- The US group required fewer attempts and a smaller volume of local anaesthetic than NS.

Background. Previous studies have demonstrated that lower local anaesthetic (LA) volumes can be used for ultrasound (US)-guided interscalene brachial plexus block (ISB). However, no study has examined whether US can reduce the volume required when compared with nerve stimulation (NS) for ISB. Our aim was to do this by comparing the minimum effective analgesic volumes (MEAVs).

Methods. After ethics approval and informed consent, patients undergoing shoulder surgery were recruited to this randomized, double-blind, up–down sequential allocation study. The volume used for both US and NS was dependent upon the success or failure of the previous block. Success was defined as a verbal rating score of 0/10, 30 min after surgery. Ten needle passes were allowed before defaulting to the opposite group. Patients received general anaesthesia. Pain scores and analgesic consumption were assessed by a blinded observer. Statistical comparisons of continuous variables were performed using Student's t-test and Mann–Whitney U-test as appropriate. Categorical variables were analysed using χ² test. MEAV values were estimated using log-transformed up–down independent pairs analysis and probit regression. Significance was assumed at P<0.05 (two-sided).

Results. The MEAV required to provide effective analgesia was significantly (P=0.034) reduced to 0.9 ml [95% confidence interval (CI) 0.3–2.8] in the US group from 5.4 ml (95% CI 3.4–8.6) in the NS group. Fewer needle passes were needed to identify the brachial plexus with US (1 vs 3; P<0.0001) and patients had less pain at 30 min after surgery (P=0.03).

Conclusions. US reduces the number of attempts, LA volume, and postoperative pain when compared with NS for ISB.

Keywords: anaesthetic techniques, regional, brachial plexus; analgesics, postoperative

Accepted for publication: 26 August 2010

Interscalene brachial plexus block (ISB) is one of the most reliable and commonly performed techniques for regional anaesthesia of the upper extremity. Given that shoulder surgery can be particularly painful, ISB is highly utilized in clinical practice as it provides anaesthesia and analgesia to the shoulder, and lateral aspects of the arm and the forearm resulting in reduction in opioid consumption and subsequent opioid-related adverse effects.

However, ISB is associated with numerous complications and adverse effects such as phrenic nerve palsy (100%), recurrent laryngeal nerve block (3–21%), stellate ganglion block (5–75%) (Horner’s syndrome), spinal (0.4–4%) and epidural anaesthesia (2.2%), and convulsions (0.2–3%) at standard volumes of 20–30 ml. Phrenic nerve block is associated with significant reductions in ventilatory function including a 21–34% decrease in forced vital capacity (FVC), 17–37% decrease in forced expiratory volume, and 15.4% decrease in peak expiratory flow rate. Therefore, ventilatory compromise resulting from ISB restricts the use of this block in patients with limited pulmonary reserve such as those with obesity, asthma, and chronic obstructive pulmonary disease (COPD) or in the elderly. Paradoxically, this patient population...
is the very population that has most to gain from the opioid-sparing benefits of ISB.

We have recently demonstrated that reducing the volume of ISB to 5 ml (compared with 20 ml) results in significantly improved preservation of post-block diaphragmatic movement (30 min after block) and postoperative FVC (when measured 30 and 60 min after general anaesthesia) for shoulder surgery with no decrease in analgesic effect. In addition, patients in the low volume group suffered significantly less hypoxia when breathing air in the recovery room (96% vs 92%; \( P < 0.05 \)) when compared with a group receiving 20 ml. However, this study made no comparison between ultrasound (US) and the current accepted gold standard, peripheral nerve stimulation (NS). Studies have demonstrated that effective analgesia after shoulder surgery is provided by low volumes of local anaesthetic (LA) when NS technique is used and it may therefore be entirely plausible that the results of our previous study could have been achieved by using the low volumes with an NS technique. It is therefore important to directly compare both US and NS for ISB to determine whether US provides any true advantage. The aim of this study was to investigate whether US facilitates the use of lower volumes of LA for ISB to produce effective analgesia after shoulder surgery when compared with an NS-guided technique. We used an up-down sequential dosing method to evaluate the minimum effective analgesic volumes (MEAVs) in each group.

Methods

After institutional research ethics board approval and written informed consent, patients undergoing arthroscopic shoulder surgery were recruited to this randomized, double-blind, up-down sequential dosing study. Inclusion criteria were age \( \geq 18 \) and \( \leq 80 \) yr and ASA I–III. Exclusion criteria included pre-existing COPD, unstable asthma, psychiatric history, renal or hepatic impairment, allergy to ropivacaine, and opioid tolerance (more than 30 mg oral morphine or equivalent per day).

Patients were randomized using a computer-generated randomization sequence using sealed, opaque envelopes to two groups each receiving an ISB with ropivacaine 0.5%. The US-guided group received the ISB using the posterior approach and the NS-guided using the technique described by Winnie. The volume used for each technique in each group depended on the success or failure of the previous block with each group starting at 10 ml with a testing interval of 1 ml. We decided on the starting volume of 10 ml because although we have demonstrated the efficacy of interscalene block previously with 5 ml of ropivacaine 0.5%, there have been no prior studies demonstrating such efficacy with low volumes using an NS technique. Successful block was defined as a pain score (11-point verbal rating scale [VRS]) of 0/10 30 min after entry to the recovery room. The patients and research assistant assessing outcomes were blinded to treatment allocation.

In the preoperative regional anaesthesia room, routine monitors including ECG, non-invasive arterial pressure, and pulse oximetry were attached, and i.v. access was established in the contralateral arm, with an infusion of 0.9% saline at a maintenance rate. Patients were given oxygen 6 litre min \(^{-1}\) via a face mask. Oral celecoxib 400 mg and oral paracetamol 1000 mg were given 1–2 h before operation as part of standardized care of shoulder surgery patients at our institution. Patients were not sedated before block placement in order that no benzodiazepine-induced reduction in respiratory volumes would occur. Blocks were performed or directly supervised by three consultant anaesthetists experienced in both NS and US-guided ISB.

In the US group, patients were positioned in the semilateral position with the neck extended to facilitate the performance of US ISB. After sterile skin preparation with chlorhexidine and skin infiltration with 1% lidocaine, US ISB was performed. A 5 cm 22 G insulated needle (B. Braun Medical Inc., Bethlehem, PA, USA) was inserted in line with the US probe in the transverse plane. An ATL (Advanced Technology Lab) 2–13 MHz probe was used to visualize the brachial plexus using a Philips HD11 XE ultrasound machine (Philips Medical Systems, Bothell, WA, USA). The LA was then injected so that spread was seen immediately posterior to or between the C5 and C6 nerve roots. An NS was attached in order to facilitate blinding with an audible signal present and at the anaesthetist’s discretion was used to confirm the needle-tip placement adjacent to the superior trunk by the presence of muscle twitch in the biceps or deltoid muscle at current \(< 1.5 \) mA. The LA was then injected so that spread was seen immediately posterior or between the C5 and C6 nerve roots.

In the NS group, patients were also positioned in the semilateral position with the neck extended to facilitate the performance of ISB and an US probe was applied on the patients’ neck (but not obstructing the anaesthetist) to ensure binding. After sterile skin preparation with chlorhexidine and skin infiltration with 1% lidocaine, NS-guided ISB was performed. A 5 cm 22 G insulated needle (B. Braun Medical Inc.) was inserted at the C6 level between the anterior and middle scalene muscles just posterior to the sternocleidomastoid muscle and inserted according to the Winnie technique. On achieving muscle contractions of the deltoid or biceps muscle, the NS (Portex Tracer III, Keene, NH, USA) current was reduced to 0.5 mA or less and the volume of ropivacaine 0.5% injected in 1 ml increments. Each time the needle was pulled back to just below the skin and re-inserted was counted as one needle pass.

In either group if >10 needle passes were required to locate the brachial plexus, the patient was excluded from the study for subsequent outcome measurements and the patient received an ISB using the converse technique with the same volume of ropivacaine 0.5%.

In each group where patients were randomized to receive 0 ml ropivacaine, 5 ml saline 0.9% was given to retain blinding.

After the performance of ISB and initial assessment, patients were taken to the operating theatre where they
were given a general anaesthetic using a standardized protocol, consisting of propofol 2–2.5 mg kg\(^{-1}\) and fentanyl 1 \(\mu\)g kg\(^{-1}\). Rocuronium 0.6–0.8 mg kg\(^{-1}\) was used for patients requiring tracheal intubation. The airway was maintained either with a laryngeal mask airway or with a tracheal tube, and the lungs were ventilated with oxygen–nitrous oxide 40–60%. Anaesthesia was maintained with 1–2% sevoflurane. Residual paralysis was antagonized at the end of the procedure with neostigmine 40 \(\mu\)g kg\(^{-1}\) and glycopyrrolate 7 \(\mu\)g kg\(^{-1}\) if required. Patients were given further intraoperative i.v. fentanyl 25 \(\mu\)g if heart rate or arterial pressure increased more than 25% above pre-induction baseline values. Skin and subcutaneous tissue at the incision sites for the arthroscopic portals were infiltrated with 10 ml of a mixture of 1% lidocaine with epinephrine and 0.25% bupivacaine before commencing surgery.

Diaphragmatic excursion was assessed by ultrasonography of the ipsilateral hemidiaphragm at the cephalad border of the zone of apposition of the diaphragm to the costal margin between the mid-clavicular and anterior axillary lines. An ATL 2–5 MHz curvilinear probe was used to visualize the diaphragm using a Philips HD11 XE ultrasound machine (Philips Medical Systems). All assessments were performed with the patient in the supine position during quiet inspiration, deep inspiration, and forceful sniff. Diaphragmatic movement was assessed both in B-mode and M-mode settings. Normal inspiratory caudad diaphragmatic excursion is designated as positive (+) motion and paradoxical cephalad motion as negative (−) motion. Each test was performed three times. Bedside spirometry using a compact spirometer (Spirolab III, Medical International Research) was performed with patients lying in a 45° semi-recumbent position, and after instruction on how to perform the test, slow vital capacity measurements were performed three times and the values averaged. Sensation of the upper extremity was assessed by pinprick using a 23 G needle testing from C4 to T1 dermatomes and scored as full sensation (=1) and loss of sensation to touch or pinprick = 0. The motor power assessment of the deltoid, biceps, triceps, finger flexion (median), finger extension (radial), and finger abduction (ulnar) was scored as movement present = 1 and no movement present = 0. All of the above assessments (diaphragmatic excursion, spirometry, sensory, and motor assessment) were done at baseline (pre-block), 10, 20, and 30 min post-block, and 30, 60, 120, and 180 min after completion of surgery.

Patients were instructed to rate their pain using an 11-point VRS ranging from 0 to 10 (0, no pain; 10, worst imaginable pain). VRS was measured at 30, 60, and 90 min after entry to the recovery room.

The primary outcome measure was pain score 30 min after entry to the recovery room and a successful block was defined as VRS = 0; conversely, a VRS score > 0 was regarded as a block failure. Patients who suffered a block failure were given the option of either a rescue US IBP or i.v. opioids until pain control was achieved. Patients who required rescue block were removed from the study for subsequent pain and analgesic consumption outcomes.

Data and results are presented as mean (sd), median (range), count, or 95% confidence interval (CI) as appropriate. Statistical comparisons of continuous variables were performed using Student’s t-test and Mann–Whitney U-test as appropriate. Categorical variables were analysed using \(\chi^2\) test. MEAV values were estimated using log-transformed up–down independent pair analysis and probit regression. Significance was assumed at \(P < 0.05\) (two-tailed).

Sample size calculations were based on a minimum detectable difference of 2.5 ml, with an sd of 2 ml with an \(\alpha\) of 0.05 and a \(\beta\) of 0.8. This gave a sample size of 12 per group, and 20 were enrolled per group to take into account the up–down design of the study.

Results

Between January and September 2009, we approached 60 patients. Out of these, 12 did not consent to enter the study, and five were not seen at the preoperative assessment unit and therefore were unable to be consented in sufficient time before the study (hospital policy precludes consenting patients for studies on the day of surgery). We recruited and randomized the remaining 43 patients for the study. Three patients were excluded due to protocol violations leaving 40 patients who completed the study (Table 1). The sequence of patients and LA volumes is described in Table 2.

The sequences of positive and negative responses recorded in consecutive patients for both groups are shown in Figure 1. The MEAV of ropivacaine 0.5% required for inter-scalene block to provide postoperative analgesia after shoulder surgery was 0.9 ml (95% CI 0.3–2.8) in the US group and 5.4 (95% CI 3.4–8.6) in the NS group (\(P = 0.034\)).

All patients in the US group required a single needle pass compared with three passes [range 1–10 passes] in the NS group (\(P < 0.0001\)). The VRS scores 30 min after entry to the recovery room were significantly greater in the NS group (median 0; range 0–6) compared with the US group (median 0; range 0–10) (\(P = 0.03\)).

No differences were apparent between groups with regard to oxygen saturation 30 min after block placement or 30 min after surgery. In addition, there were no differences in slow vital capacity between groups either post-block or post-

<table>
<thead>
<tr>
<th>Table 1. Patient characteristics</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>Age (yr) [mean (sd)]</td>
</tr>
<tr>
<td>Gender (F/M)</td>
</tr>
<tr>
<td>Weight (kg) [mean (sd)]</td>
</tr>
<tr>
<td>Height (cm) [mean (sd)]</td>
</tr>
<tr>
<td>Surgical duration (min)</td>
</tr>
<tr>
<td>Fentanyl administered after</td>
</tr>
<tr>
<td>initial 1 (\mu)g kg(^{-1}) ((\mu)g) (sd)</td>
</tr>
<tr>
<td>ASA I/II/III</td>
</tr>
</tbody>
</table>
Ultrasound reduces local anaesthetic volume for ISB

**Table 2** Sequence of patients and LA volumes. *First four patients where >10 needle passes were required, defaulted to US. Successful block occurred but volume reduced for next patient (see the Results section). **Subsequent patients where >10 needle passes required and patient data excluded after block performance. ***0, Sham injection (5ml 0.9% saline). †In Patient 23, where we used 1 ml successfully, we realized after consultation that we needed to use 0 ml for the next US patient to continue the sequence effectively and be able to calculate MEAV<sub>50</sub>. We needed to reapply to the REB for permission to use a sham procedure. In the meantime, we continued the study but used (successfully) in Patient 28 a further volume of 1 ml before obtaining permission to use sham.

<table>
<thead>
<tr>
<th>Patient number</th>
<th>Technique</th>
<th>Volume</th>
<th>Needle passes</th>
<th>Total fentanyl (µg)</th>
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surgery and no differences were seen in motor or sensory block between groups. No block-related adverse events were experienced in either group.

Discussion
This study found that an US-guided technique significantly reduced the LA volume requirement for successful ISB when compared with an NS-guided technique. In addition, the use of US significantly reduces the number of needle passes required, increases the ability to successfully localize the brachial plexus, and also produces a more effective analgesic block after surgery, despite the very low volumes of LA used.

Shoulder surgery has previously been demonstrated to be one of the more painful surgical procedures, especially when performed as a day-surgery procedure.\(^1\) ISB provides significant analgesic benefits\(^2\) and a number of recent studies\(^5\)–\(^8\) using US-guided techniques have demonstrated that lower volumes of LA can preserve respiratory function. However, until now, it has not been clear whether these results could also be obtained using a traditional NS-guided technique. A study of US-guided interscalene block either using 5 or 20 ml ropivacaine 0.5% found that although postoperative analgesia was identical in the first 24 h after surgery, there was a significant reduction in adverse respiratory events in the 5 ml group.\(^5\) That study was criticized because both groups were performed with US and critics have questioned whether successful low volume blocks are equally possible with NS. This study demonstrates that although it is possible to use low volumes with both techniques, the US technique is superior to NS in this regard. In fact, despite all blocks being performed or supervised by experienced practitioners in NS-guided techniques, we found that a significant number of NS patients needed to switch groups after reaching 10 needle passes. We initially assumed that the inability to locate the plexus within this method would be rare, and with the first three patients (patient numbers 5, 13, and 17) where this occurred, we used an intention-to-treat model, subsequently reducing volume in the NS group for the next patient. It became obvious that the inability to obtain an NS endpoint at 10 needle passes or less was common and that we would unfairly favour the volume in the NS group if we continued with this method. Therefore, for subsequent patients where the superior trunk could not be localized within 10 needle passes (patient numbers 21, 24, 25, and 33), we removed the patients from further study, placed the block using US, and used the same volume for the next patient in that group. In the NS group seven of 20 patients required an US-guided block because a suitable NS endpoint was not obtained at 10 needle passes or less. Patients in the NS group who required more than 10 needle passes were successfully completed with US on each occasion.

In this study, we limited the number of needle passes for each technique and it may be that normally in NS-guided blocks, anaesthetists frequently underestimate the number of needle passes that they need to make for successful nerve location. Recent research has also demonstrated that false-negative responses can often occur with NS. Patients fear regional anaesthesia for many reasons. In our experience, the fear of pain during block performance is often mentioned as a reason for avoiding peripheral nerve blocks. Reducing the number of needle passes will inevitably reduce block-related pain, increase acceptance of regional techniques, and possibly reduce adverse events due to misplacement of needle tip during block performance.

The higher pain scores in the NS group in the present study possibly relates to less precise placement of LA, even though successful NS was performed. Other studies have demonstrated that US is associated with greater brachial plexus block success when compared with NS techniques; this may be related to less accurate placement of LA in the NS group.\(^10\) In addition, the greater pain scores in the NS group in the present study may indicate that even when

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**Fig 1** Up–down sequence for both US and NS with dotted lines indicating 95% CIs.
Ultrasound reduces local anaesthetic volume for ISB

the superior trunk was successfully located and despite higher LA volumes, the deposition of LA was less precise.

Unlike our previous study, in this study we found no differences in motor and sensory block and no difference in respiratory impairment between groups. This may be because in both groups, we started at a 10 ml volume and reduced down to much lower volumes. In addition, the numbers of patients and difference in LA volume between groups may have led to lack of power to find any true difference in respiratory impairment. The main aim of this study was to determine whether a difference in MEAV exists between NS and US using up-down methodology and it may be inappropriate to use this design to make any interpretation about other endpoints where no significant differences were found.

It was surprising that such low volumes of LA could produce effective analgesia in the US group in this study; in fact, five patients had successful ISB with 1 ml of ropivacaine 0.5%. A recent study also found that very low volumes (1 ml) were required to anaesthetize peripheral nerves with severe pain on awakening after surgery.

In this study at a very strict level (VAS > 0) in order to limit as much as possible the likelihood of patients being in severe pain on awakening after surgery.

It could be questioned whether the intraoperative fentanyl and pre-incision LA given to the arthroscopic port sites affected the results of this study. We feel that this was unlikely to be the case, as the patients who received sham blocks, who despite intraoperative fentanyl and local infiltration still had VRS scores of 5, 5, and 7 in the recovery room and all required rescue blocks. Also, if the fentanyl and local anaesthesia had produced any effect, this would have minimized any difference between the groups, rather than causing one group to be advantaged. The addition of fentanyl and the infiltration, if anything, should reduce differences between groups and reduce the power of the study. Therefore, our ability to demonstrate a significant difference further emphasizes the advantages of US. However, practitioners should note that the volumes quoted in this study represent MEAV50 and not MEAV95 values and that all patients also received multimodal analgesia including incisional LAs. Larger volumes of LA are therefore likely required for most patients until further studies demonstrate efficacy of ultra-low volumes of LA.

The results of this study represent the effective LA volumes in 50% of patients and allow us to compare US and NS efficiently by using a much smaller sample than would be required to find the effective volumes in 95%. In addition, future studies need to determine the duration of block with very low volume US-guided techniques and also the effect of concentration on both block effectiveness and duration. It would be interesting to determine whether a low volume US-guided block with a subsequent continuous infusion could both institute and maintain good analgesia without significant respiratory impairment.

In summary, this study demonstrates that an US-guided interscalene block significantly reduces the number of needle passes, required LA volume, and postoperative pain compared with an NS-guided technique.

Conflict of interest
None declared.

Funding
The study was supported by a grant from the Physicians Services Incorporated Foundation to U.S. and C.J.L.M.

References
2 Ilfeld BM, Morey TE, Wright TW, Chidgey LK, Ennekink FK. Continuous interscalene brachial plexus block for postoperative pain control at home: a randomized, double-blinded, placebo-controlled study. Anesth Analg 2003; 96: 1089–95


PhD by publication
10 messages

Colin McCartney <cjlmccartney@gmail.com>  25 June 2013 07:36
To: Vincent Chan <mail2vincechan@aol.com>, "Perlas, Anahi" <Anahi.Perlas@uhn.ca>, Nick Lo <LoN@smh.ca>, "Brull, Richard" <Richard.Brull@uhn.ca>

Dear Vincent, Ricky, Anahi and Nick,
I am in the process of applying to University of Edinburgh for a PhD by publication and have put together a proposed thesis entitled "Evolution and Impact of ultrasound guidance on feasibility, efficacy and safety of ultrasound brachial plexus anaesthesia" (see enclosed).
I have been asked by the university to justify my authorship with regard to my contribution to conception and design, data acquisition, analysis, interpretation, writing and final approval for each of the studies.
In the enclosed excel file I have written my interpretation for each of these areas for the listed studies. Although most of the studies are clear there are three where I am not principal author and I would value your evaluation and if ok, your agreement. The university may ask your opinion and I want to make sure you agree with my assessment prior to my submission.
In particular I would value your thoughts on the studies by Perlas et al (2006), Chan et al (2007) and Lo et al (2008) with regard to these areas. Please let me know if you agree with my memory of my contribution in each of these studies and of course, correct me where necessary on the enclosed excel file.
Thank you in advance for looking at this for me.
Sincerely,
Colin

2 attachments

- McCartney PhD by publication synopsis.pdf
  60K
- PhD research contributions.xlsx
  42K

Brull, Richard <Richard.Brull@uhn.ca>  25 June 2013 11:07
To: Colin McCartney <cjlmccartney@gmail.com>

Looks good to me. Good luck!

From: Colin McCartney <cjlmccartney@gmail.com><mailto:cjlmccartney@gmail.com>>
Date: Tuesday, 25 June, 2013 7:36 AM
To: Vincent Chan <mail2vincechan@aol.com><mailto:mail2vincechan@aol.com>>, "Perlas, Anahi" <Anahi.Perlas@uhn.ca><mailto:Anahi.Perlas@uhn.ca>>, "Lo, Nick - St. Michael's Hospital" <LoN@smh.ca><mailto:LoN@smh.ca>>, RB <richard.brull@uhn.ca><mailto:richard.brull@uhn.ca>>
Subject: PhD by publication

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Colin McCartney <cjmccartney@gmail.com>
To: "Brull, Richard" <Richard.Brull@uhn.ca>

Thanks

Perlas, Anahi <Anahi.Perlas@uhn.ca>
To: Colin McCartney <cjmccartney@gmail.com>

Hi, Colin,

Yes, your contribution to our study published in 2006 is well represented. Good luck with your PhD application!!

All the best,

Anahi

Anahi Perlas, MD, FRCPC

Associate Professor, Dept of Anesthesia, University of Toronto

Director, Clinical Regional Anesthesia Program

Department of Anesthesia, Toronto Western Hospital

University Health Network

399 Bathurst St., Toronto, ON
**M5T 2S8**

*phone (416) 603 5118*

*fax (416) 603 6494*

*e-mail anahi.perlas@uhn.on.ca*

---

**From:** Colin McCartney [mailto:cjlmcCartney@gmail.com]
**Sent:** Tuesday, June 25, 2013 7:36 AM
**To:** Vincent Chan; Perlas, Anahi; Lo, Nick - St. Michael's Hospital; Brull, Richard
**Subject:** PhD by publication

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---

Colin McCartney <cjlmcCartney@gmail.com>  
To: "Perlas, Anahi" <Anahi.Perlas@uhn.ca>  
26 June 2013 11:05

Thanks Anahi,
Colin
[Quoted text hidden]

---

Colin McCartney <cjlmcCartney@gmail.com>  
To: Vincent Chan <mail2vincechan@aol.com>, Nick Lo <LoN@smh.ca>  
26 June 2013 11:06

Vincent, Nick,
Let me know when you have the time.
Colin
[Quoted text hidden]

---

Vincent Chan <mail2vincechan@aol.com>  
To: Colin McCartney <cjlmcCartney@gmail.com>  
26 June 2013 11:17

Your interpretation of your contribution to the 2007 study is fine with me.
All the best with your PhD application.
Regards

Vincent

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On 2013-06-26, at 11:06 AM, Colin McCartney wrote:

Vincent, Nick,
Let me know when you have the time.
Colin

-------- Forwarded message --------
From: Perlas, Anahi <Anahi.Perlas@uhn.ca>
Date: 26 June 2013 09:59
Subject: RE: PhD by publication
To: Colin McCartney <cjlmccartney@gmail.com>

Hi, Colin,

Yes, your contribution to our study published in 2006 is well represented. Good luck with your PhD application!!

All the best,

Anahi

Anahi Perlas, MD, FRCPC

Associate Professor, Dept of Anesthesia, University of Toronto
Director, Clinical Regional Anesthesia Program

Department of Anesthesia, Toronto Western Hospital

University Health Network

399 Bathurst St., Toronto, ON,

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fax (416) 603 6494

e-mail anahi.perlas@uhn.on.ca

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Sent: Tuesday, June 25, 2013 7:36 AM
To: Vincent Chan; Perlas, Anahi; Lo, Nick - St. Michael's Hospital; Brull, Richard
Subject: PhD by publication

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In particular I would value your thoughts on the studies by Perlas et al (2006), Chan et al (2007) and Lo et al (2008) with regard to these areas. Please let me know if you agree with my memory of my contribution in each of these studies and of course, correct me where necessary on the enclosed excel file.

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Sincerely,

Colin

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Opinions, conclusions or other information contained in this e-mail may not be that of the organization.

Colin McCartney <cjlmccartney@gmail.com>
To: Vincent Chan <mail2vincechan@aol.com>

Many thanks Vincent,
Colin

Nick Lo <LoN@smh.ca>
To: Colin McCartney <cjlmccartney@gmail.com>

Hi Colin,

Looks good. Good luck with your PhD!

Cheers,

Nick

Nick Lo, MD FRCPC

26 June 2013 12:23

27 June 2013 09:01
Sent from my iPhone

[Quoted text hidden]

<McCartney PhD by publication synopsis.pdf>
<PhD research contributions.xlsx>

Colin McCartney <cjmccartney@gmail.com> 27 June 2013 09:36
To: Nick Lo <LoN@smh.ca>

Thanks Nick

[Quoted text hidden]