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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 χ^2 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

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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,[1] 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.[2]

However, ISB is associated with numerous complications and adverse effects[3] 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.[4] 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

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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.[5] 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[6] 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[5] and the NS guided using the technique described by Winnie.[7] 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.[5] 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.[5] 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 blinding. 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.[7] 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 μg 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 μg kg^{-1} and glycopyrrolate 7 μg kg^{-1} if required. Patients were given further intraoperative i.v. fentanyl 25 μg 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 ISB 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 χ^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 α of 0.05 and a β 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 interscalene 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 1 Patient characteristics

	Group I: US	Group II: NS
Age (yr) [mean (SD)]	50.7 (15.8)	57.7 (10.8)
Gender (F/M)	7/14	8/10
Weight (kg) [mean (SD)]	93.8 (26.9)	85.5 (19.3)
Height (cm) [mean (SD)]	173.5 (8.9)	170.9 (10.4)
Surgical duration (min)	141.6 (52.2)	144 (48)
Fentanyl administered after initial 1 μg kg^{-1} (μg) (SD)	42 (74)	77 (105)
ASA I/II/III	7/12/1	5/12/3

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 $MEAV_{50}$. 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

Patient number	Technique	Volume	Needle passes	Total fentanyl (μg)	Block success (VAS=0 at 30 min after PACU entry)
1	US	10	1	120	Y
2	NS	10	1	200	Y
3	US	9	1	250	Y
4	US	8	1	150	Y
5	NS→US*	9	>10	250	Y
6	US	7	1	350	Y
7	US	6	1	150	Y
8	US	5	1	250	Y
9	NS	8	3	450	N
10	US	4	1	200	Y
11	US	3	1	150	N
12	NS	9	1	500	Y
13	NS→US*	8	>10	200	Y
14	US	4	1	250	Y
15	NS	7	3	300	N
16	NS	8	2	100	Y
17	NS→US*	7	>10	350	Y
18	US	3	1	400	Y
19	US	2	1	225	Y
20	NS	6	2	250	Y
21	NS→US**	5	>10		Data excluded after block
22	NS	5	1	500	Y
23	US†	1	1	200	Y
24	NS→US**	4	>10		Data excluded after block
25	NS→US**	20	>10		Data excluded after block placement-protocol violation (LA vol)
26	NS	4	4	100	N
27	NS	5	7	300	Y
28	US	1	1	50	Y
29	Excluded	Protocol violation			
30	US	0***	1	150	N
31	NS	4	2	160	Y
32	US	1	1	200	N
33	NS→US**	3	>10		Data excluded after block
34	NS	3	2	350	N
35	NS	4	2	150	N
36	US	2	1	150	Y
37	US	1	1	250	Y
38	US	0***	1	150	N
39	US	1	1	250	Y
40	US	0***	1	450	N
41	Excluded	Protocol violation			
42	US	1	1	150	Y
43	NS	5	2	100	Y

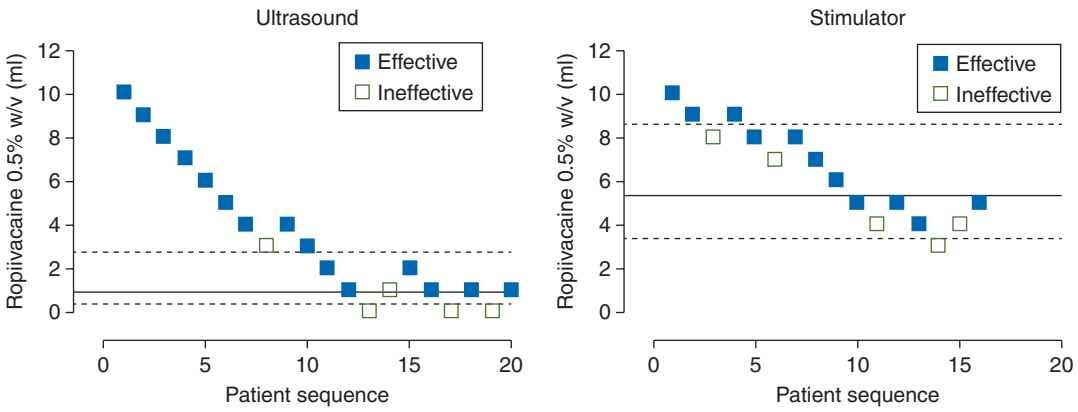

Fig 1 Up–down sequence for both US and NS with dotted lines indicating 95% CIs.

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.[9] 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

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

Unlike our previous study,[5] in the present 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[11] also found that very low volumes (1 ml) were required to anaesthetize peripheral nerves with US-guided axillary block. However, no comparison with NS was made. It is likely that for smaller peripheral nerves, only small volumes of LA are necessary to produce effective block as demonstrated recently by several authors.[11–14]

This study has a number of limitations. We can make minimal interpretation regarding block duration with low volumes of LA because all patients were discharged within 3 h of surgery completion. However, since most blocks took place at least 3 h before surgical completion, we can say that the low volume techniques do last at least 6 h and possibly much longer. This needs to be assessed in a further study. Secondly, our failure rate to locate the superior trunk with NS was high and this may have been, as discussed earlier, related to our decision to move to the US technique after 10 needle passes. In addition, the success rate after surgery may have been much higher in the NS group had we used standard volumes of LA (20+ ml).

As discussed previously, in the early part of this study, we treated failure to locate the plexus with >10 needle passes and conversion to the US technique in an intention-to-treat manner. However, we quickly realized that the number of patients where we could not locate the superior trunk with NS was going to be greater than expected, and if we continued in the initial manner, we would produce a false downward bias for the $MEAV_{50}$ calculation in the NS group. Therefore, for the purposes of this study, the $MEAV_{50}$ in the NS group may be artificially low but importantly this does not change the overall results of the study.

The use of a sham ISB in this study was justified because patients were also receiving multimodal analgesia (celecoxib and paracetamol), were allowed additional boluses of fentanyl during their general anaesthetic, and were assessed as soon as they entered post-anaesthesia care unit (PACU) for any pain. We intentionally set the criteria for block failure 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 $MEAV_{50}$ and not $MEAV_{95}$ 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.

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