

Comparison of Ultrasound Guided Supraclavicular Brachial Plexus Block with and without Peripheral Nerve Stimulation (PNS) Guidance: A randomised controlled trial

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Abstract

Background:

The integration of Ultrasound (US) and Peripheral Nerve Stimulation (PNS) is often used to enhance the safety and success of peripheral nerve blocks (PNB). However, the added clinical benefit of PNS in the era of high-resolution ultrasound remains a subject of debate. We aimed to compare the procedural efficiency and clinical efficacy of US-guided PNB versus US supplemented with PNS.

Methods:

In this prospective, randomised controlled trial, 44 adult patients scheduled for upper limb surgery were randomised 1:1 to Group US (n = 22) or Group US + PNS (n = 22). Three were excluded after randomisation and before intervention, leaving 41 patients for per-protocol analysis (Group US, n = 20; Group US + PNS, n = 21). Participants were not informed of their allocation. The primary outcome was the success rate of the block. Secondary outcomes were the time to onset of sensory and motor blockade, the duration of block performance, the frequency of needle re-adjustment, the rate of complications, and the requirement for rescue analgesia or conversion to general anaesthesia.

Results:

The mean duration of block performance was shorter in the US group than the US + PNS group (8.5 ± 2.7 vs 18.0 ± 3.5 minutes; $p < 0.001$). Median sensory (18 vs 18 minutes; $p = 0.67$) and motor block onset (25.5 vs 24 minutes; $p = 0.77$) did not differ significantly between groups. Within the US + PNS group, needle re-adjustment was required in 66.7% of cases, primarily triggered by an initial motor response below 0.4 mA ($p < 0.001$). The overall success rate was 95% in the US group and 100% in the US + PNS group ($p = 0.30$). No block-related neurological complications occurred in either group, no patient required conversion to general anaesthesia, and the single partial block in the US group was managed successfully with local infiltration of the surgical field.

Conclusion:

The use of ultrasound guidance alone for peripheral nerve blocks significantly reduces procedural time without affecting the onset or success rate of the blockade. The addition of PNS frequently necessitates corrective needle re-adjustments to maintain safety thresholds, thereby increasing the technical burden and performance time without offering a superior clinical outcome.

Trial registration

ClinicalTrials.gov NCT07083934, registered 13 June 2025. Available at <https://clinicaltrials.gov/study/NCT07083934>

Background

Peripheral nerve blockade (PNB) with local anaesthetic is an established method of providing anaesthesia and analgesia to the limbs and was well described by the late twentieth century. Its adoption in routine practice nonetheless remained limited, owing to unreliability, a high rate of complications and block failure attributable to the lack of accurate techniques of nerve localisation available at that time. (1) Wider recognition of regional anaesthesia followed the commercial availability of newer methods of nerve localisation, in particular peripheral nerve stimulation (PNS) and ultrasound (US) imaging. Acceptance of PNB as a sole anaesthetic technique for limb surgery increased further over the past decade with advances in US technology, including compact and portable units, higher image resolution and needle recognition software.

Ultrasound guidance offers several practical advantages over nerve stimulation alone, including direct real-time visualisation of the target anatomy, the needle pathway and its relation to adjacent structures, and the spread of local anaesthetic, together with the capacity for immediate needle re-adjustment. (2) These features permit a safer and more effective distribution of local anaesthetic around the target nerve. (3) This advantage has led to a decline in the use of PNS guidance in regional anaesthesia practice in recent years.

Notwithstanding these advantages, ultrasound guidance has its own limitations. Image resolution is constrained at greater depth because adequate tissue penetration often requires lower transducer frequencies, while increasing attenuation progressively reduces the returning signal. (4) Deeper targets may also require a steeper angle of needle insertion, reducing the needle beam angle and consequently the echogenic return from the needle shaft and tip during an in-plane approach. (5) Sonographic appearances also do not reliably exclude placement of the needle tip within the nerve, since ultrasound cannot resolve injection into the nerve stroma from injection into a fascicle, and intraneural injection may result in nerve injury. (6)

These limitations may be addressed by the concurrent use of PNS guidance. PNS delivers a small pulse of electrical current through the needle tip, which stimulates an adjacent neural structure and produces contraction of the corresponding muscle group, thereby assisting identification of the target nerve. A stimulating current of approximately 1 mA for superficial nerves and 1.5 to 2 mA for deeper nerves, delivered at a pulse duration of 0.1 ms and a frequency of 2 Hz, is sufficient to elicit the desired motor response. (7) A motor response obtained at higher currents may cause patient discomfort and may also mislead the operator, since neural structures can be stimulated across intervening tissue and fascial planes. The needle tip may therefore be judged close to the nerve while it remains at a distance, and local anaesthetic deposited there may produce an inadequate or failed block. (8) The stimulating current also carries information on intrafascicular or intraneural needle placement. Bigeleisen et al. reported a minimum stimulating threshold, expressed as median [interquartile range], of 0.60 mA [0.40 to 1.0] at extraneural positions and 0.30 mA [0.20 to 0.40] at intraneural positions, a difference of 0.30 mA that was statistically significant. (9) A lower limit for the stimulating current may therefore serve as a safety margin, below which no motor response should be elicited before injection of local anaesthetic.

We therefore designed a randomised controlled trial to compare ultrasound guidance with and without the addition of PNS guidance for supraclavicular brachial plexus block. The primary objective was to compare the success rate of the block between the two techniques. The secondary objectives were to compare the time to onset of sensory and motor blockade, the duration of the block procedure, the frequency of needle re-adjustment in the dual guidance group, the rate of complications including nerve injury, the requirement for intraoperative rescue analgesia and the rate of conversion to general anaesthesia.

Methods

Study design, setting and ethical approval

This prospective, randomised controlled trial was conducted in the operating rooms of the Aga Khan University Hospital (AKUH), Karachi. Ethical approval was obtained from the departmental anaesthesia research cell and the AKUH Ethical Review Committee under reference number 2024-9043-30909. The trial was conducted in accordance with the principles of the Declaration of Helsinki and with good clinical practice. The protocol was prospectively registered at ClinicalTrials.gov (NCT07083934) on 13 June 2025 and first posted on 24 July 2025, before enrolment of the first participant. Recruitment ran from 25 July 2025 until March 2026, at which point the planned sample size was reached. The trial was designed as a superiority comparison; no equivalence or non-inferiority margin was pre-specified. The full trial protocol is publicly available from the ClinicalTrials.gov record; no separate statistical analysis plan was prepared, and the analysis is described in full below. Patients and members of the public were not involved in the design, conduct or reporting of this trial.

Study population and sample size

The sample size was calculated using the OpenEpi software function for the comparison of two means. A reliable a priori estimate of the between group difference in block success was not available from comparable trials of supraclavicular brachial plexus block, in which reported success rates in both ultrasound and dual guidance groups consistently approach the upper limit of the scale. The time to onset of sensory blockade, reported as a continuous variable with established between group estimates in the available literature, was therefore used as the basis for the calculation. The corresponding mean (standard deviation) values for time to onset of sensory blockade were taken as 10 (2.4506) minutes for the ultrasound group and 7.5 (1.2253) minutes for the ultrasound plus peripheral nerve stimulation group, derived from the randomised trial of axillary brachial plexus block reported by Demirelli et al, in which the corresponding values were originally presented as median (interquartile range) and converted to mean (standard deviation) using the methods described by Luo et al and Wan et al. (3, 10, 11) A 1:1 allocation ratio between the two groups was applied. The calculation used a confidence level of 99% and a statistical power of 95%, in preference to the conventional 95% and 80%, in order to reduce the probability of both type I and type II error and to provide a conservatively sized cohort for the planned comparison. On this basis, a minimum sample size of 44 patients, 22 per group, was determined.

Adult patients aged 18 years and older, of American Society of Anesthesiologists (ASA) physical status I to IV, scheduled for elective surgical procedures of the mid to lower arm, elbow, forearm, wrist or hand were eligible for recruitment. Patients with pre-existing neuropathy, coagulopathy, local infection at the injection site or cognitive impairment precluding first party consent were excluded, as were patients anticipated to require postoperative ventilatory support in the intensive care unit.

Randomisation and allocation concealment

Patients were allocated in a 1:1 ratio to the ultrasound guided group (Group US) or the ultrasound plus peripheral nerve stimulation group (Group US + PNS) using block randomisation with a fixed block size of four. The allocation sequence was generated using a computer based random number generator. The sequence was generated by one of the investigators, who took no part in data collection, and was not accessible to the clinician who enrolled participants or to the operator who performed the blocks. Allocation concealment was maintained by sequentially numbered, sealed and opaque envelopes, which were opened only after enrolment of the participant. The block size was not disclosed to the recruiting clinician until completion of the trial. Participants were not informed of their group allocation, although the trial was otherwise open label. The operator performing the block was necessarily aware of the group assignment given the nature of the intervention under study, and also performed all assessments of sensory and motor blockade.

Recruitment

Recruitment commenced after approval from the institutional ethical review committee and the clinical trials unit. The operating room schedule for the following day was reviewed and patients listed for surgical procedures involving the mid to lower arm, elbow, forearm, wrist or hand were identified for potential inclusion. Eligible patients were interviewed in the ward following admission for surgery. Patients who met the inclusion and exclusion criteria were considered for participation, and the primary surgeon was informed in each instance. Where the primary surgeon consented to participation, the patient was provided with a written information sheet and consent form, and the procedure together with its potential advantages and disadvantages was explained, including an explicit statement of the voluntary nature of participation. Patients who provided written informed consent were enrolled, and patient identifiers were removed from the trial dataset.

Block technique

In the operating room, standard ASA monitoring was applied, comprising non-invasive blood pressure (NIBP) measurement, continuous electrocardiography (ECG) and pulse oximetry. Intravenous access was secured in the contralateral upper limb with a 20 or 22 gauge cannula for background fluid administration and emergency access. The patient was positioned supine with slight rotation of the head towards the contralateral side. All blocks were performed under strict aseptic conditions by a consultant anaesthetist with more than ten years of experience in supraclavicular brachial plexus block.

In the ultrasound group, a high frequency linear array transducer was positioned in the supraclavicular fossa to obtain a short axis view of the subclavian artery and the first rib, and the brachial plexus was identified as a cluster of elliptical hypoechoic trunks and divisions lateral to the subclavian artery. Subcutaneous infiltration of 1 to 2 mL of 2% lignocaine was performed 1 cm lateral to the transducer through a 27 gauge needle to reduce discomfort on insertion of the block needle. An insulated block needle (Stimuplex Ultra 360, 21 gauge, 80 mm, B. Braun Melsungen AG, Melsungen, Germany) was introduced in plane to the transducer in a lateral to medial direction and advanced towards the junction of the first rib and the subclavian artery, targeting the neural cluster of the brachial plexus. Once the operator was satisfied with the position of the needle tip, negative aspiration was performed to exclude inadvertent intravascular puncture, and 25 mL of 0.5% bupivacaine was injected in incremental aliquots around the neural cluster under direct sonographic observation of hydrodissection and the spread of local anaesthetic. Where the spread of local anaesthetic around the neural cluster was incomplete, the needle was repositioned and further injection was performed until the intended circumferential spread was achieved.

In the ultrasound plus peripheral nerve stimulation group, the procedure was conducted in the same manner, with one additional step. Nerve stimulation was delivered using a Stimuplex HNS 12 nerve stimulator (B. Braun Melsungen AG, Melsungen, Germany), set to a pulse duration of 0.1 ms and a stimulation frequency of 2 Hz. Once the operator was satisfied with the position of the needle tip on ultrasound, a stimulating current of 1.0 mA was delivered through the block needle, with the objective of eliciting a motor response in the arm, the forearm or the hand. Failure to elicit a motor response at 1.0 mA prompted repositioning of the needle until a motor response was obtained. Once a motor response was established, the stimulating current was reduced incrementally to 0.4 mA. A motor response persisting at or below 0.4 mA was interpreted as a marker of close needle to nerve proximity and prompted repositioning of the needle until that response was abolished, with preservation of a motor response within the stimulation window of 0.5 to 1.0 mA before injection of local anaesthetic.

Outcomes and assessment

The primary outcome was the success rate of the block. A successful block was defined as the achievement of complete sensory and motor blockade in the three tested nerve territories within 60 minutes of completion of local anaesthetic injection, with the planned surgical procedure completed without supplementation. A partially successful block was defined as complete sensory and motor blockade on pre-incision testing, with intraoperative surgical pain requiring supplementary local anaesthetic infiltration of the surgical field. A failed block was defined as the absence of sensory and motor blockade in the tested territories on pre-incision testing, requiring an alternative anaesthetic technique.

The secondary outcomes were the time to onset of sensory blockade, the time to onset of motor blockade, the duration of the block procedure, the frequency of needle re-adjustment in the ultrasound plus peripheral nerve stimulation group, the rate of complications, the requirement for intraoperative

rescue analgesia and the rate of conversion to general anaesthesia. The duration of the block procedure was defined as the interval from insertion of the block needle through the skin to completion of local anaesthetic injection and declaration by the operator to the theatre team that the block procedure was complete.

The progression of sensory blockade was assessed by evaluating the absence of cold sensation using an ice pack in the median, ulnar and radial nerve distributions, with comparison against the contralateral arm. The progression of motor blockade was assessed in the same three nerve territories. Median nerve function was tested by thumb opposition, ulnar nerve function by finger abduction, and radial nerve function by extension of the wrist and fingers, again with comparison against the contralateral arm. Both assessments were performed at three-minute intervals after completion of local anaesthetic injection until sensory and motor blockade were established in each of the three tested nerve territories. The time to onset of sensory blockade was defined, for each tested nerve territory, as the interval from completion of injection to the loss of cold sensation in that territory, and the time to onset of motor blockade as the interval from completion of injection to the loss of the corresponding voluntary movement. Once sensory and motor blockade had been established across the three tested nerve territories, the operating surgeon was given clearance to proceed with the surgical procedure.

Assessment of harms

Any intraoperative analgesic requirement was documented. After completion of surgery, patients were transferred to the post anaesthesia care unit (PACU), where surgical pain was assessed. Immediate procedural complications, comprising vascular puncture, clinical features of pneumothorax and symptoms or signs of local anaesthetic systemic toxicity, were sought during performance of the block and in the immediate post-procedural period. As part of routine regional anaesthesia service practice at the study institution, all patients receiving peripheral nerve blockade are reviewed by dedicated regional anaesthesia personnel until documented block resolution, defined as the return of sensory and motor function in the blocked nerve territories. All patients enrolled in the present trial underwent this routine review. Block related neurological complications were pre-specified as paraesthesia persisting beyond the expected timeline of block resolution, and any sensory or motor deficit within the distribution of the blocked nerves not consistent with that timeline. These features were specifically sought at each review.

Changes to the registered protocol

Three changes were made to the registered protocol before data collection commenced. Assessment of blockade was restricted to the median, ulnar and radial nerve territories. At the supraclavicular level the brachial plexus lies at the level of the trunks and divisions, from which all terminal branches subsequently arise, so complete sensory and motor blockade across these three territories provides confident evidence of blockade of the plexus as a whole. Assessment of the musculocutaneous territory was therefore judged to add no further information, and its exclusion is consistent with the assessment protocols used in comparable trials of supraclavicular block. Sensory and motor blockade were assessed at three-minute intervals rather than at one-minute and two-minute intervals respectively, since

the operator, who also performed the assessments, could not reliably complete testing of three nerve territories for both modalities within a shorter cycle, and motor blockade was assessed by nerve-specific tests rather than by gross movement of the elbow, wrist and fingers. A partially successful block was defined against intraoperative adequacy rather than the presence of patchy blockade on testing.

Statistical analysis

The analysis was conducted on a per protocol basis, comprising all randomised patients who received the allocated intervention and completed the planned block procedure. Three randomised patients were excluded from the analysed population before the intervention was delivered, comprising two patient withdrawals and one surgeon refusal, with the distribution of exclusions across the two study groups detailed in the participant flow diagram. Analyses were performed using IBM SPSS Statistics version 26 (IBM Corporation, Armonk, NY, USA). No interim analyses were undertaken and no stopping guidelines were applied. There were no missing outcome data among the analysed patients, and no imputation was therefore required.

Continuous variables, including age, weight, height, body mass index, duration of block performance, time to onset of sensory blockade, time to onset of motor blockade and duration of surgery, were assessed for distribution using the Shapiro-Wilk test in conjunction with visual inspection of histograms and Q-Q plots. Normally distributed variables were summarised as mean and standard deviation, and non-normally distributed variables as median and interquartile range. Categorical variables, including gender, comorbidity status, type of surgical procedure, block success, requirement for needle re-adjustment and stimulation threshold response, were summarised as frequency and percentage.

Between group comparisons of continuous variables were performed using the independent samples t-test where distributional assumptions were satisfied, and using the Mann-Whitney U test where they were not. Between group comparisons of categorical variables were performed using the chi-square test of association, with Fisher's exact test substituted where the expected count in any cell of the contingency table fell below five. Effect estimates were reported with 95% confidence intervals, comprising the risk difference for block success, the mean difference for normally distributed continuous outcomes, and the Hodges-Lehmann median difference for onset times, for which the discrete three-minute assessment interval produced heavily tied data. Within the ultrasound plus peripheral nerve stimulation group, a pre-specified comparison was made between patients who required needle re-adjustment and those who did not, using the same tests. All statistical tests were two-sided and a p value below 0.05 was considered to indicate statistical significance.

Use of artificial intelligence

A large language model, Claude (Opus 5, Anthropic), was used during preparation of this article, at all times under the direction of the authors. Its contribution was editorial in nature and included refining expression, aligning the structure of the manuscript with the CONSORT 2025 reporting guideline and with the formatting conventions of this journal, checking the reported figures for internal agreement, and

confirming the reference list against the original publications. No clinical data were produced, gathered or modified by the tool at any stage. Every methodological judgement, every interpretation of the findings and every conclusion drawn is the work of the authors, who have reviewed and approved the version submitted and who stand behind its factual accuracy, its originality and its scholarly integrity.

Results

Participant flow

A total of 68 patients were assessed for eligibility, of whom 24 were excluded. The remaining 44 patients were randomised to Group US (n = 22) and Group US + PNS (n = 22). In the US group, two patients did not receive the allocated intervention, owing to patient withdrawal in one instance and surgeon refusal in the other. In the US + PNS group, one patient withdrew before the intervention. Twenty patients in Group US and 21 patients in Group US + PNS were therefore included in the final analysis (Fig. 1).

Baseline characteristics

The demographic profile, comprising age, sex, weight, height and body mass index, was comparable between the two groups, as was the prevalence of hypertension, diabetes mellitus, ischaemic heart disease, heart failure, end stage renal disease and chronic obstructive pulmonary disease (Table 1). End stage renal disease was present in 15 patients (75.0%) in Group US and 14 patients (66.7%) in Group US + PNS, and brachiocephalic arteriovenous fistula formation was correspondingly the most frequent surgical procedure, performed in the same numbers in each group.

Table 1
Baseline characteristics of the two study groups

Characteristic	Group US (n = 20)	Group US + PNS (n = 21)
Age, years, mean (SD)	58.4 (14.3)	55.5 (15.4)
Sex, n (%)		
Male	13 (65.0)	15 (71.4)
Female	7 (35.0)	6 (28.6)
Weight, kg, mean (SD)	75.6 (10.1)	75.0 (11.3)
Height, cm, mean (SD)	162.2 (9.3)	163.8 (10.8)
Body mass index, kg/m ² , mean (SD)	28.7 (3.0)	28.0 (3.9)
Comorbidity, n (%)		
Hypertension	15 (75.0)	13 (61.9)
Diabetes mellitus	9 (45.0)	8 (38.1)
Ischaemic heart disease	8 (40.0)	9 (42.9)
Heart failure	5 (25.0)	5 (23.8)
End stage renal disease	15 (75.0)	14 (66.7)
Chronic obstructive pulmonary disease	0 (0.0)	1 (4.8)
Surgical procedure, n (%)		
Brachiocephalic arteriovenous fistula formation	15 (75.0)	14 (66.7)
Distal radius fixation	0 (0.0)	4 (19.0)
Radius or ulna fixation	3 (15.0)	1 (4.8)
Distal humerus fixation	2 (10.0)	1 (4.8)
Forearm debridement	0 (0.0)	1 (4.8)
SD, standard deviation; Group US, ultrasound guided group; Group US + PNS, ultrasound plus peripheral nerve stimulation group.		

Block success

A successful block was achieved in 19 patients (95.0%) in Group US and in all 21 patients (100.0%) in Group US + PNS, a risk difference of – 5.0 percentage points (95% CI – 23.6 to 11.0; p = 0.30). The corresponding risk ratio was 0.95 (95% CI 0.83 to 1.09), estimated with a continuity correction because no failures occurred in Group US + PNS; the odds ratio is not estimable for the same reason. One patient in Group US had a partially successful block, in which blockade was satisfactory on pre-incision testing

but surgical pain developed intraoperatively. This was managed by infiltration of the surgical field with local anaesthetic, which was sufficient for the intended procedure to be completed. No block was classified as failed, and no patient in either group required conversion to general anaesthesia (Table 2).

Table 2
Primary and secondary outcomes

Outcome	Group US (n = 20)	Group US + PNS (n = 21)	Effect estimate (95% CI) ^a	p
Primary outcome				
Successful block, n (%)	19 (95.0)	21 (100.0)	-5.0 (- 23.6 to 11.0)	0.30
Partially successful block, n (%)	1 (5.0)	0 (0.0)	—	—
Failed block, n (%)	0 (0.0)	0 (0.0)	—	—
Secondary outcomes				
Duration of block procedure, min, mean (SD)	8.5 (2.7)	18.0 (3.5)	-9.55 (- 11.53 to - 7.58)	< 0.001
Sensory block onset, min, median (IQR) ^b				
Median nerve	18 (15–18)	18 (15–18)	0 (0 to 0)	0.67
Ulnar nerve	18 (15–18)	18 (15–18)	0 (0 to 0)	0.54
Radial nerve	18 (15–18)	18 (15–18)	0 (0 to 0)	0.86
Motor block onset, min, median (IQR) ^b				
Median nerve	25.5 (24–27)	24 (24–27)	0 (0 to 0)	0.77
Ulnar nerve	27 (24–27)	24 (24–27)	0 (0 to 0)	0.43
Radial nerve	27 (27–30)	27 (27–30)	0 (0 to 0)	0.91
Needle re-adjustment, n (%) ^c	—	14 (66.7)	—	—
Intraoperative rescue analgesia, n (%)	1 (5.0)	0 (0.0)	—	—
Conversion to general anaesthesia, n (%)	0 (0.0)	0 (0.0)	—	—
Complications, n (%)	0 (0.0)	0 (0.0)	—	—
Other				
Duration of surgery, min, mean (SD)	128.9 (35.6)	122.1 (39.9)	6.85 (- 17.07 to 30.77)	0.57

Outcome	Group US (n = 20)	Group US + PNS (n = 21)	Effect estimate (95% CI) ^a	p
Primary outcome				
The statistic reported is stated in each row label.				
^a Effect estimates are expressed as Group US minus Group US + PNS. The estimate for block success is the risk difference in percentage points with a Newcombe hybrid score interval. Estimates for duration of block procedure and duration of surgery are mean differences in minutes. Estimates for onset times are Hodges-Lehmann median differences in minutes				
^b Confidence intervals for onset times are of zero width because assessment at three-minute intervals produced a heavily tied distribution of onset values				
^c Needle re-adjustment was assessed only in Group US + PNS and no between-group estimate applies				
Em dash (—) indicates not applicable.				
CI, confidence interval; IQR, interquartile range; SD, standard deviation; Group US, ultrasound guided group; Group US + PNS, ultrasound plus peripheral nerve stimulation group.				

Duration of block performance and onset of blockade

The mean duration of the block procedure was shorter in Group US than in Group US + PNS, at 8.5 (2.7) minutes compared with 18.0 (3.5) minutes, a mean difference of – 9.55 minutes (95% CI – 11.53 to – 7.58; $p < 0.001$).

The onset of sensory and motor blockade did not differ between the groups in any tested nerve territory. Median sensory onset was 18 minutes in both groups in the median, ulnar and radial territories. Median motor onset ranged from 24 to 27 minutes, with radial motor onset the latest at 27 minutes in both groups. The Hodges-Lehmann median difference in onset was zero minutes for all three sensory and all three motor territories, with confidence intervals of zero width, reflecting the three-minute assessment interval and the resulting tied distribution of onset times (Table 2).

Harms

No vascular puncture, pneumothorax or clinical features of local anaesthetic systemic toxicity were observed in either group. Routine post-procedural review to documented block resolution identified no block related neurological complications in any patient in either study group (Table 2).

Duration of surgery

The mean duration of surgery was 128.9 (35.6) minutes in Group US and 122.1 (39.9) minutes in Group US + PNS, a mean difference of 6.85 minutes (95% CI – 17.07 to 30.77; $p = 0.57$) (Table 2).

Needle re-adjustment and stimulation characteristics

Within Group US + PNS, needle re-adjustment was required in 14 of 21 patients (66.7%, 95% CI 45.4 to 82.8). Patients requiring re-adjustment were compared with those who did not, these subgroups being defined by procedural events occurring after randomisation rather than by allocation.

In the re-adjustment subgroup, 12 patients (85.7%) had elicited a motor response at or below 0.4 mA, compared with none of the seven patients who required no re-adjustment ($p < 0.001$). An absence of motor response at the target current of 1.0 mA was observed in 4 patients (28.6%) in the re-adjustment subgroup and in none of those requiring no re-adjustment ($p = 0.12$). The final median minimum stimulating current before injection of local anaesthetic was comparable between the two subgroups, at 0.6 mA (IQR 0.5 to 0.7) in those requiring re-adjustment and 0.6 mA (IQR 0.5 to 0.6) in those who did not ($p = 0.94$) (Table 3).

Table 3

Stimulation threshold responses and minimum stimulating current in patients requiring and not requiring needle re-adjustment within Group US + PNS

Variable	Needle re-adjustment (n = 14)	No needle re-adjustment (n = 7)	p ^a
No motor response at 1.0 mA, n (%)	4 (28.6)	0 (0.0)	0.12
Motor response at or below 0.4 mA, n (%)	12 (85.7)	0 (0.0)	< 0.001
Minimum stimulating current, mA, median (IQR)	0.6 (0.5–0.7)	0.6 (0.5–0.6)	0.94
The statistic reported is stated in each row label.			
Subgroups were defined by procedural events occurring after randomisation rather than by allocation.			
^a Categorical comparisons were performed using the chi-square test with Fisher's exact test where the expected cell count was below five, and the comparison of minimum stimulating current using the Mann-Whitney U test			
IQR, interquartile range; Group US + PNS, ultrasound plus peripheral nerve stimulation group.			

Discussion

In this randomised controlled trial comparing US guided supraclavicular brachial plexus block performed with and without PNS, the addition of PNS showed no demonstrable advantage in block success or in the onset of sensory or motor blockade, while more than doubling the duration of the block procedure. Successful blockade was achieved in 95.0% of the US group and 100.0% of the dual guidance group, a risk difference of – 5.0 percentage points with a confidence interval spanning – 23.6 to 11.0. Median onset of block was identical between the groups in every tested nerve territory. The mean duration of the block procedure was 9.55 minutes shorter with US alone. Within the dual guidance group, PNS prompted

needle re-adjustment in two thirds of patients, and in the great majority of those cases the trigger was a motor response elicited at or below 0.4 mA.

The absence of an efficacy difference is consistent with the most directly comparable study available. Beach and colleagues examined this question at the same anatomical site, assessing whether a motor response to nerve stimulation predicted success in patients receiving ultrasound guided supraclavicular block. They found successful blockade in 88% of patients with a motor response and 90% of those without, with a relative risk of 1.09 (95% CI 0.79 to 1.51; $P = 0.52$). (12) Their conclusion was that a positive motor response does not increase block success when the supraclavicular plexus is adequately visualised, although they acknowledged a potential role for stimulation when ultrasound visualisation is suboptimal. (12) Nearly two decades later, Gadsden reached a similar conclusion, reporting that adding nerve stimulation to ultrasound does not generally improve block success except for targets that are difficult to visualise, while describing a shift in its role from nerve localisation towards monitoring for needle nerve contact. (13)

While the evidence specific to the supraclavicular approach supports the present findings, the broader literature is more heterogeneous. A systematic review and meta analysis by Wang and colleagues included randomised trials across upper and lower limb blockade and found no significant difference in overall or sensory block success with the addition of nerve stimulation to ultrasound, although dual guidance was associated with a longer procedure time. (14) The review included heterogeneous block techniques and anatomical targets, with a substantial proportion of lower limb and axillary blocks, which limits direct extrapolation to the supraclavicular approach. A national survey of Swiss anaesthetists further found dual guidance to be the preferred approach for peripheral nerve localisation in routine practice. (15) The findings presented here therefore differ from prevailing practice in that setting, despite the absence of demonstrated improvement in block efficacy at the supraclavicular site.

The trial was not designed as an equivalence or non-inferiority study and no margin was pre-specified. The finding should therefore be interpreted as an absence of a demonstrated advantage for dual guidance under the conditions studied, rather than as evidence that the two techniques are equivalent. The confidence interval for the difference in block success ranged from a 23.6 percentage point disadvantage to an 11.0 percentage point advantage for ultrasound alone. Thus, although no significant difference was detected, the study was not precise enough to rule out a meaningful difference between the techniques. This limitation is partly inherent to the question being studied rather than specific to the present trial. A systematic review of ultrasound guided brachial plexus techniques by Albrecht and colleagues, comprising 25 randomised trials and 1948 participants, found a successful blockade rate of approximately 92%, with no difference between axillary, infraclavicular and supraclavicular approaches. (16) When success rates are already high, there is relatively little scope for further improvement, making it difficult to demonstrate superiority without a large sample.

The difference in procedural duration was the most consistent finding of the trial and the only one that reached statistical significance. The additional time is likely to reflect the procedural steps associated

with nerve stimulation, including current adjustment, assessment of the motor response, and needle repositioning when the desired response is not obtained. Comparable findings have been reported across different block sites and patient populations. Alfred and colleagues, comparing ultrasound with nerve stimulation for supraclavicular block, reported procedure times of 11.57 ± 2.75 minutes and 21.73 ± 4.84 minutes, respectively. (17) Thomas and colleagues found that ultrasound guidance required substantially less time than nerve stimulation for interscalene block in a residency training environment. (18) Şengel and colleagues, in a retrospective series of 240 paediatric infraclavicular blocks, found that adding nerve stimulation to ultrasound increased procedure time from 6.1 ± 0.8 to 8.31 ± 0.82 minutes without corresponding differences in operative time, block duration or postoperative analgesic outcomes. (19) Although a difference of several minutes is unlikely to be important for an individual case, its cumulative effect may become relevant in a high volume operating environment. Additional procedural time represents greater utilisation of operating room resources and may reduce the time available for subsequent cases. Operating room time is a costly healthcare resource, while efficient turnover is an important determinant of operating room productivity and hospital financial performance. (20, 21) These considerations become particularly relevant when the additional time required for dual guidance is not accompanied by a corresponding gain in efficacy or safety.

The needle re-adjustment finding requires careful handling, because read at face value it appears to argue against the trial's own conclusion. Peripheral nerve stimulation prompted repositioning in 14 of 21 patients, and in 12 of those 14 the trigger was a motor response elicited at or below 0.4 mA. In every one of those cases an experienced operator, working with a favourable sonographic window, had already judged the needle position satisfactory. Nerve stimulation therefore supplied positional information that ultrasound alone did not provide, and in its absence local anaesthetic would have been injected at those positions. The equivalence of the final minimum stimulating current between the re-adjustment and no re-adjustment subgroups, at a median of 0.6 mA in both, indicates that repositioning consistently relocated the needle into a comparable stimulation window.

The interpretation of this finding depends on what a stimulating current threshold can and cannot establish. Bigeleisen and colleagues, working at the same anatomical site, reported a median extraneural threshold of 0.60 mA (IQR 0.40–1.0) and a median intraneural threshold of 0.30 mA (IQR 0.20–0.40). (9) The 0.4 mA threshold used in the present trial lies at the upper limit of the reported intraneural range and was selected as a conservative threshold for prompting needle repositioning. It does not, however, establish intraneural placement. Wiesmann and colleagues showed in a porcine brachial plexus model that minimal current intensity could not distinguish needle to nerve contact from intraneural needle placement. (22) Tsai and colleagues found that a motor response could be absent despite intraneural needle placement at currents as high as 1.7 mA. (23) Robards and colleagues similarly found no motor response in 16.7% of patients despite documented intraneural needle placement, including at stimulation currents of 1.5 mA. (24) Sala-Blanch and colleagues found intraneural injection in 16 of 17 patients receiving popliteal sciatic block at stimulation currents of 0.3 to 0.44 mA, without clinical or electrophysiological evidence of nerve injury. (25) A sub-threshold motor response is therefore best regarded as a warning of close needle to nerve proximity and a reasonable

indication for repositioning, rather than as a diagnostic statement about the relationship of the needle tip to the nerve.

Understood in this way, the re-adjustment finding and the efficacy finding are not in conflict. Nerve stimulation functioned in this trial as a proximity monitor rather than as a localising technique, and its contribution was to flag needle positions that were closer to neural structures than the operator intended, rather than to identify the plexus or improve the resulting block. This is consistent with the role proposed for nerve stimulation in contemporary practice. (13) Current guidance also supports ultrasound visualisation of the needle tip as an important component of procedural safety. (26) No block related neurological complication occurred in either group, so the trial cannot establish whether the needle positions flagged by stimulation would have resulted in harm had injection proceeded. The conclusion that ultrasound guidance alone is clinically adequate in this setting rests on the absence of a demonstrated difference in block success or onset together with the absence of observed complications, and not on any claim that proximity warnings are without value.

The absence of incremental benefit should be considered in relation to two factors. The first is operator experience. The value of any confirmatory adjunct is likely to depend on the accuracy of the primary technique, and its contribution may be greater when sonographic identification is less secure. The Swiss survey found that use of dual guidance decreased as self-estimated expertise in regional anaesthesia increased. (15) Orebaugh and colleagues found that ultrasound combined with nerve stimulation reduced block performance time for residents compared with nerve stimulation alone, while Luyet and colleagues demonstrated different learning curves for ultrasound and nerve stimulation. (27, 28) These findings suggest that the relative value of the two approaches may differ during earlier stages of training. All blocks in the present trial were performed by a single consultant with more than ten years of experience in this technique, within an established ultrasound guided regional anaesthesia service at the study institution, a previous audit of which reported effective analgesia and a low complication rate across 299 ultrasound guided blocks, including 49 supraclavicular blocks. (29) The findings should therefore be interpreted in the context of experienced operator performance. The second factor is the anatomical target. The supraclavicular brachial plexus is relatively superficial and its major neural elements can usually be visualised clearly with ultrasound. In this setting, ultrasound provides positional information that may leave limited additional contribution for stimulation to make. The findings should not therefore be extrapolated to deeper techniques or to patients in whom the sonographic window is poor. Nerve stimulation may retain a useful confirmatory role when target nerves are difficult to visualise. (13, 30)

The composition of the study population warrants specific comment, since three quarters of the ultrasound group and two thirds of the dual guidance group had end stage renal disease, and brachiocephalic arteriovenous fistula formation was the most frequent procedure. Brachial plexus blockade has an established role in anaesthesia for arteriovenous fistula creation. Aitken and colleagues, in an observer blinded randomised controlled trial, found primary patency at three months in 84% of fistulae created under brachial plexus block compared with 62% under local anaesthesia, with an

odds ratio of 3.3 (95% CI 1.4–7.6). (31) This benefit has been attributed in part to the sympathectomy like effect of the block, with associated arterial and venous dilatation and increased blood flow. (32) The question of how best to perform the block is therefore of practical consequence in this population. There is a further consideration specific to this cohort. Patients with diabetic neuropathy may have altered responses to electrical nerve stimulation. Sites and colleagues described two diabetic patients in whom ultrasound confirmed appropriate perineural needle placement, but no motor response was obtained until stimulation currents of 2.4 and 2.6 mA were reached. (33) Nearly half of the patients in each group had diabetes mellitus. Absence of a motor response at 1.0 mA may therefore be a less reliable indicator of needle to nerve distance in this population and may partly explain the four patients in the re-adjustment subgroup who required repositioning for this reason. The implications of a low current motor response in neuropathic patients are less certain, as the available evidence does not establish a quantitative relationship between stimulation threshold and needle to nerve distance in this population. Nerve stimulation may therefore provide less reliable localisation information in patients with neuropathy, particularly when a motor response is absent, which is a further reason for caution when generalising these findings to unselected surgical cohorts.

The trial has a number of strengths. Block randomisation with allocation concealment by sequentially numbered, sealed and opaque envelopes limits selection bias. The performance of all blocks by a single experienced operator removes inter-operator variability between the treatment arms. The sample size calculation used a confidence level of 99% and a statistical power of 95% in preference to conventional parameters, providing a conservatively sized cohort. The trial was prospectively registered before enrolment of the first participant, and effect estimates with confidence intervals are reported for the primary outcome and for the continuous secondary outcomes.

Several limitations require acknowledgement. The trial was conducted at a single centre by a single operator, and the results apply to experienced performance of a superficial block under routinely favourable sonographic conditions. The sample size was calculated on time to onset of sensory blockade rather than on the registered primary outcome of block success. This decision reflected the limited comparative data available for estimating the between group difference in supraclavicular block success at the design stage. Reported success rates in the comparative literature are generally high, with Albrecht and colleagues reporting a pooled success rate of 92% across 25 randomised trials. (16) This is a constraint on the available evidence rather than a defect specific to this trial, but its consequence is that the study had limited power to detect a difference in block success and the comparison should be interpreted accordingly. No non-inferiority margin was pre-specified, so no claim of equivalence can be sustained. Sensory and motor blockade were assessed at three minute intervals, so onset was recorded only to a three minute resolution. This interval was longer than the 2.5 minute difference used for the sample size calculation, meaning that smaller between group differences could not be resolved. The resulting clustering of onset times also contributed to the zero width of the distribution free confidence interval for the median difference. The trial was open label. The operator was necessarily aware of group allocation and also performed all assessments of sensory and motor blockade, so outcome ascertainment was not blinded. This carries a potential for expectation bias in the

recorded onset times, and in the decision to re-adjust the needle in the dual guidance group, although the latter was governed by pre-specified stimulation criteria. Participants were not informed of their allocation, but concealment cannot be assumed, since the motor responses elicited during nerve stimulation are perceptible to an unsedated patient. Onset was assessed against objective endpoints, namely loss of cold sensation and loss of specified voluntary movements, which limits but does not remove the scope for bias. Horner syndrome, hoarseness and hemidiaphragmatic paresis were not systematically assessed. This is a material omission at this anatomical site, since hemidiaphragmatic paresis has been reported in 53% of patients after nerve stimulator guided supraclavicular block and in none after a controlled ultrasound guided technique in the same trial. (34) The clinical consequences of phrenic nerve palsy may be greater in patients with limited cardiopulmonary reserve. (35) The trial can therefore offer no comment on the incidence of these effects. Finally, the trial was designed and powered to compare efficacy rather than neurological safety, and the routine post procedural review applied here was directed at identifying clinically apparent events rather than formally estimating their incidence.

The questions left open define a clear agenda for further study. A definitive comparison of block success would require a multicentre trial designed prospectively as a non-inferiority study, with a pre-specified margin justified against the high baseline success rate of supraclavicular block and with operators across a range of experience. Further studies should also examine deeper blocks and situations in which the target or needle is difficult to visualise, where the additional contribution of nerve stimulation may be greater. (13, 30) Systematic assessment of hemidiaphragmatic paresis and other regional adverse effects should be incorporated, particularly in patients with limited cardiopulmonary reserve. The potential role of additional safety adjuncts also warrants prospective evaluation. Opening injection pressure monitoring has been shown to detect needle to nerve contact during femoral and interscalene blockade and may provide information complementary to ultrasound and nerve stimulation. (36, 37) Future trials combining these approaches could determine whether additional physiological signals improve recognition of potentially hazardous needle positions and, more importantly, whether this translates into improved clinical safety.

Conclusion

In adult patients undergoing upper limb surgery, the addition of peripheral nerve stimulation to ultrasound guidance for supraclavicular brachial plexus block did not produce a demonstrable difference in block success or in the onset of sensory or motor blockade, while significantly increasing the duration of the block procedure. Within the dual guidance group, peripheral nerve stimulation prompted needle re-adjustment in two thirds of cases, predominantly in response to motor responses elicited at low stimulating currents that suggested close needle to nerve proximity not identified by ultrasound alone. For routine supraclavicular brachial plexus block performed by an experienced operator under favourable sonographic conditions, ultrasound guidance alone provides clinically adequate block performance. Peripheral nerve stimulation retains a defensible selective role as a monitor of needle to nerve proximity, particularly in clinical scenarios in which sonographic conditions are anticipated to be less favourable.

Abbreviations

ASA

American Society of Anesthesiologists

AKUH

Aga Khan University Hospital

CI

confidence interval

CONSORT

Consolidated Standards of Reporting Trials

ECG

electrocardiography

IQR

interquartile range

PACU

post anaesthesia care unit

PNB

peripheral nerve block

PNS

peripheral nerve stimulation

SD

standard deviation

US

ultrasound

Declarations

Ethics approval and consent to participate

Ethical approval was obtained from the departmental anaesthesia research cell and the Ethical Review Committee of Aga Khan University Hospital, Karachi, under reference number 2024-9043-30909. The trial was conducted in accordance with the principles of the Declaration of Helsinki. Written informed consent to participate was obtained from all participants.

Consent for publication

Not applicable.

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Author Contribution

MAS conceived the study, contributed to its design, and contributed to data interpretation and preparation of the manuscript. HMMT contributed to data collection, data analysis and preparation of the manuscript. AR supervised the conduct of the trial and contributed to its design and to critical revision of the manuscript. All authors read and approved the final manuscript.

Acknowledgement

N/A

Data Availability

The datasets generated and analysed during the current study are not publicly available, as they contain individual patient clinical and procedural data for which explicit consent for public data sharing was not obtained from participants. The data are, however, available from the corresponding author on reasonable request, subject to approval from the Ethical Review Committee of Aga Khan University Hospital, Karachi.

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Figures

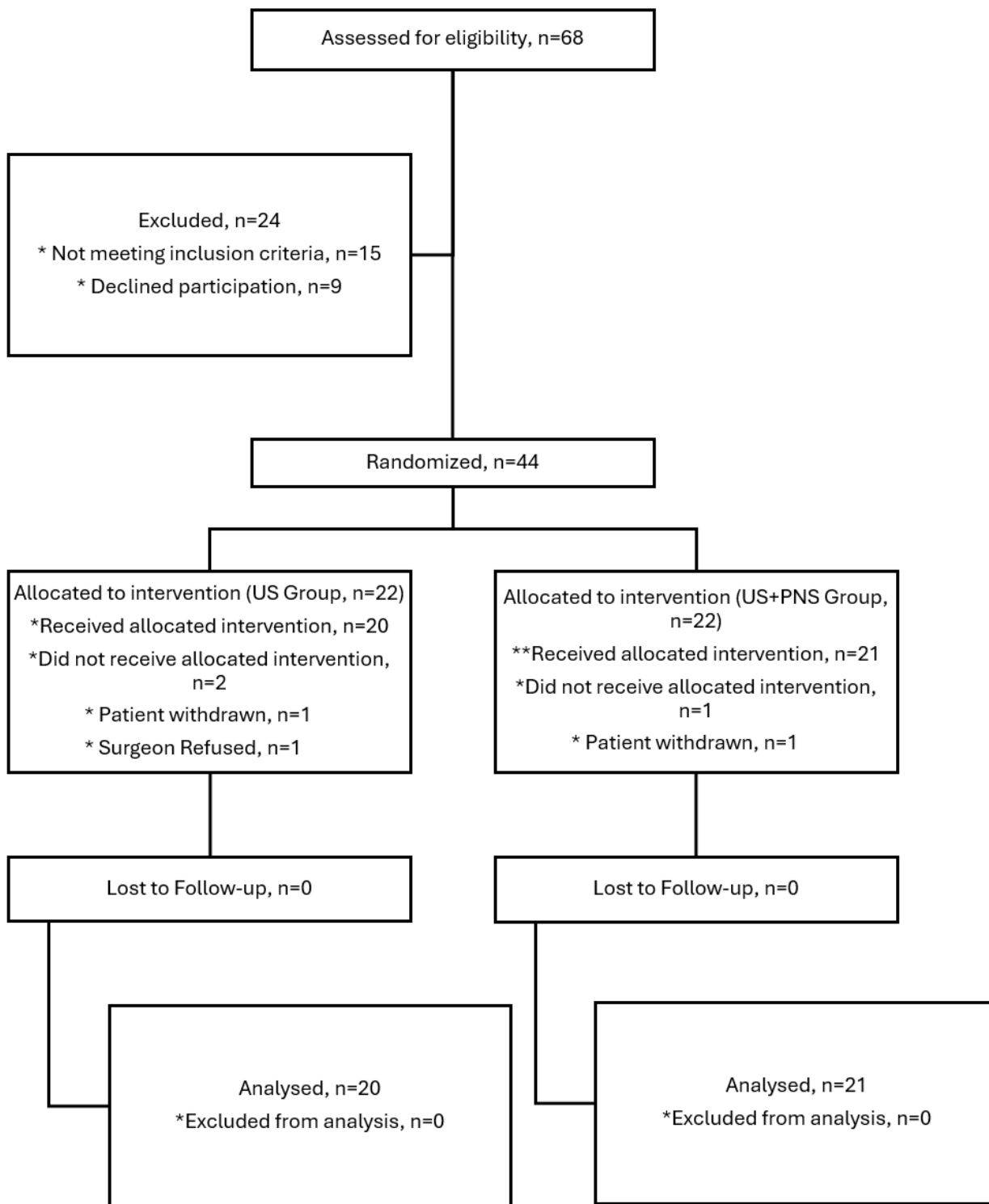


Figure 1

CONSORT Flow Diagram of Participant Recruitment and Randomization.