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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Objectif *: Le but de cette étude est de déterminer si l'échoguidage en temps réel améliore le taux de succès du bloc du plexus brachial par approche axillaire.*

Méthode *: Des patients devant subir une chirurgie élective de la main ont été randomisés en trois groupes. Des blocs axillaires ont été effectués en utilisant : trois points de réponses motrices dans le groupe neurostimulateur (NS), l'échoguidage en temps réel dans le groupe échographie (EG), et l'échographie combinée à la stimulation nerveuse dans le troisième groupe (EGNS). Suite à l'administration d'une solution standardisée contenant de la lidocaïne 2 % avec épinéphrine (1:200 000) et de la bupivacaïne 0,5 % (total 42 mL), les fonctions sensitives et motrices ont été évaluées par un observateur neutre toutes les cinq minutes pendant 30 min. Un bloc réussi a été défini comme la perte complète de sensation dans la distribution des nerfs médian, radial et cubital après 30 min. La nécessité d'une anesthésie locale et générale supplémentaire ainsi que les effets négatifs post-bloc ont été documentés.*

Résultat *: Chez les 188 patients qui ont terminé l'étude, le taux de succès du bloc a été plus élevé dans les groupes EG et EGNS (82,8 % et 80,7 %) que dans le groupe NS (62,9 %) ($P = 0,01$ et 0,03 respectivement). Un nombre moins élevé de patients des groupes EG et EGNS a nécessité des blocs nerveux supplémentaires et/ou une anesthésie générale. Après l'opération, les hématomes et douleurs axillaires ont été plus fréquemment observés dans le groupe NS.*

Conclusion *: Cette étude démontre que l'échoguidage, avec ou sans neurostimulation concomitante, améliore de façon significative le taux de succès du bloc du plexus brachial par approche axillaire.*

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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.[1,2] 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.[3–5] 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[6,7] for brachial plexus blockade in the interscalene,[8] supraclavicular,[9] and infraclavicular regions.[10,11] While ultrasound has been reported to be useful for axillary block,[12,13] 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.

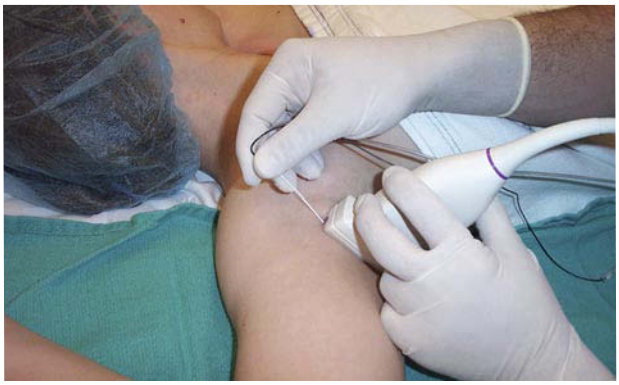

FIGURE 1A Ultrasound probe and block needle position during ultrasound guided axillary block.

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 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. 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 1 A) and Philips HDI 5000 unit (Philips Medical Systems ATL Ultrasound, Bothell, WA, USA). The probe surface was covered by a sterile

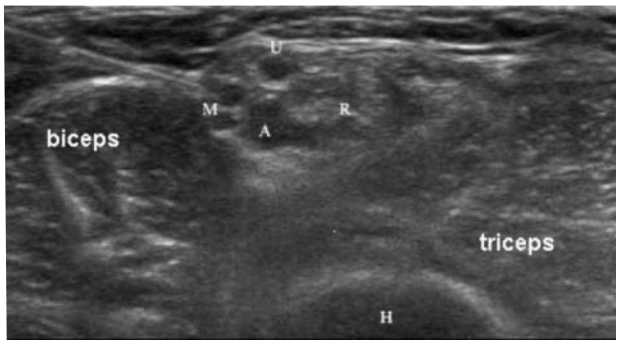

FIGURE 1B A transverse sonogram showing the median (M), radial (R) and ulnar (U) nerves around the axillary artery (A) and the block needle (arrowheads) in contact with the median nerve.

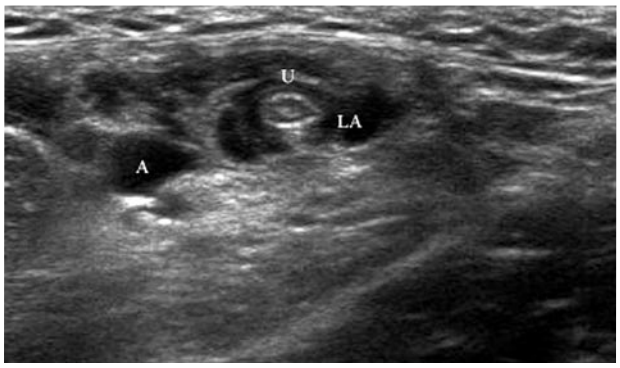

FIGURE 1D A transverse sonogram showing local anesthetic spread (LA) around the ulnar nerve (U); A = axillary artery.

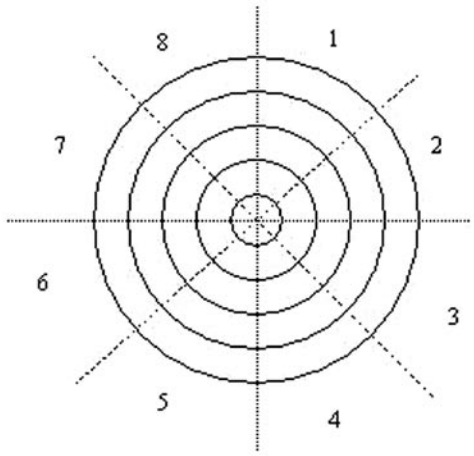

FIGURE 1C A schematic drawing of eight pie-chart sectors to describe nerve locations around the axillary artery (A).

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 1 B). 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 1 B). Location of individual nerves was recorded according to a schematic drawing of eight pie-chart sectors (Figure 1 C).[14] 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 1 D).

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,

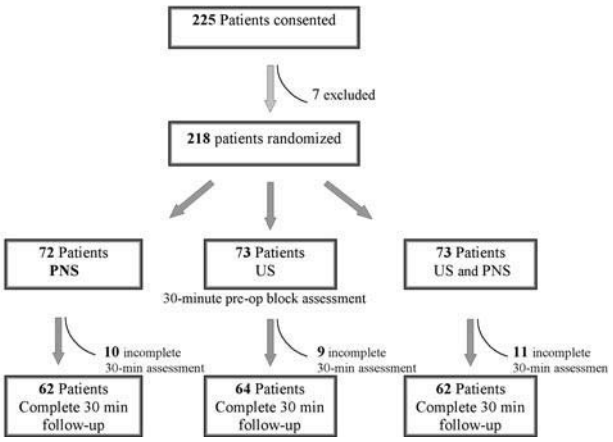

FIGURE 2 Patient randomization and follow-up.

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)

	NS *(n = 62)*	*US* *(n = 64)*	*USNS* *(n = 62)*	*P-value*
Gender (male / female)	30 / 32	43 / 21	37 /25	0.20
Age (yr)	49.3 ± 14.6	44.3 ± 13.5	45.2 ± 13.0	0.10
Weight (kg)	74.9 ± 13.8	78.2 ± 18.9	79.6 ± 17.5	0.32
Height (cm)	167.0 ± 10.9	168.1 ± 23.8	169.7 ± 9.7	0.68
Body mass index (kg·m^2)	27.0 ± 4.6	27.1 ± 5.1	27.7 ± 5.8	0.70
Surgical time (min)	50.8 ± 24.9	57.5 ± 28.5	55.8 ± 3.6	0.43
Intraoperative				
fentanyl dose (ug)	39.5 ± 50.1	42.7 ± 43.3	44.4 ± 50.5	0.85
propofol dose (mg)	51.7 ± 105.8	69.8 ± 117.9	81.0 ± 121.0	0.36
midazolam dose (mg)	1.2 ± 1.2	1.4 ± 1.7	1.3 ± 1.4	0.80

NS = nerve stimulator Group, US = real-time ultrasound guidance in the ultrasound Group and USNS = combined ultrasound and nerve stimulation Group.

TABLE II Success rates, procedure time, and requirement for block supplementation

	NS (*n* = 62)	*US* (*n* = 64)	*USNS* (*n* = 62)
Block procedure time (min)	11.2 ± 4.2	9.3 ± 4.0*	12.4 ± 4.8
P-value (compared to NS)		< 0.01	
Complete sensory block in all three nerves at 30 min	62.9% (39/62)	82.8%* (53/64)	80.7%* (50/62)
Odds ratio/95% CI, compared to NS		2.84 (1.24-6.51)	2.84 (1.24-6.51)
P-value (compared to NS)		0.01	0.03
Successful surgical anesthesia without supplementation	85.5% (53/62)	95% (59/62)	92% (57/62)
P-value (compared to NS)		0.07	0.26
Supplementation			
General anesthesia	1	1	3
Rescue block	8	2	2
Total	9	3	5
Sensory block at 30 min			
Median nerve	51 (82.3%)	60 (93.8%)	59 (95.2%)
P-value (compared to NS)		0.06	0.04
Ulnar nerve	51 (82.6%)	62 (96.9%)	59 (96.7%)
P-value (compared to NS)		< 0.01	0.01
Radial nerve	42 (69.4%)	55 (85.9%)	52 (83.9%)
P-value (compared to NS)		0.03	0.09
Motor block at 30 min			
Median nerve	42/49 (85.7%)	43/56 (94.6%)	38/43 (88.4%)
P-value (compared to NS)		0.25	0.21
Ulnar nerve	43/49(87.8%)	53/56 (94.6%)	41/42 (97.6%)
P-value (compared to NS)		0.30	0.18
Radial nerve	42/51 (82.4%)	50/58(86.2%)	42/46 (91.3%)
P-value (compared to NS)		0.58	0.59

NS = nerve stimulator Group, US = real-time ultrasound guidance in the ultrasound Group and USNS = combined ultrasound and nerve stimulation Group. CI = confidence interval.

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 USNS 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. Schwemmer *et al.*[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.*[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.*[17] reported success rates of 73% and 70% for ultrasound and nerve stimulator guided axillary blocks, respectively, and Marhofer *et al.*[18] reported a 100% success rate for pediatric infraclavicular block guided by either technique. Soeding *et al.*[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,[16] hasten block onset,[18] improve block quality,[16] prolong block duration[18] and decrease block related complications.[17,19]

Only one previously published study has shown a higher success rate with ultrasound guided axillary block. Sites *et al.*[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.*,[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.[21,22] Anatomic studies also show the presence of septae within the axillary sheath which are thought to act as a diffusion barrier to local anesthetic spread.[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 predetermined stimulating current threshold in Group USNS. Our chosen injection endpoint – based primarily 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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