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Ultrasound-Guided Root/Trunk (Interscalene) Block for Hand and Forearm Anesthesia

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Abstract

Background—Historically, the anterolateral interscalene block—deposition of local anesthetic adjacent to the brachial plexus roots/trunks—has been used for surgical procedures involving the shoulder. The resulting block frequently failed to provide surgical anesthesia of the hand and forearm, even though the brachial plexus at this level included all of the axons of the upper extremity terminal nerves. However, it remains unknown whether deposition of local anesthetic adjacent to the seventh cervical root or inferior trunk results in anesthesia of the hand and forearm.

Methods—Using ultrasound guidance and a needle-in-plane posterior approach, a Tuohy needle was positioned with the tip located between the deepest and next-deepest visualized brachial plexus root/trunk, followed by injection of mepivacaine (1.5%). Grip strength and the tolerance to cutaneous electrical current in 5 terminal nerve distributions were measured at baseline and then every 5 minutes following injection for a total of 30 minutes. The primary end point was the proportion of cases in which the interscalene nerve block resulted in a decrease in grip strength of at least 90%, and hand and forearm anesthesia (tolerance to >50 mA of current in all 5 terminal nerve distributions) within 30 minutes. The primary hypothesis was that a single-injection interscalene brachial plexus block produces a similar rate of anesthesia of the hand and forearm to the published success rate of 95% for other brachial plexus block approaches.

Results—Of 55 subjects with blocks placed per protocol, all had a successful block of the shoulder as defined by inability to abduct at the shoulder joint. Thirty-three subjects had measurements at 30 minutes following local anesthetic deposition, and only 5 (15%) of these subjects had a surgical block of the hand and forearm ($P < 0.0001$; 95% confidence interval [CI]: 6–33%). We therefore reject the hypothesis that the interscalene block as performed in this study provides equivalent anesthesia to the hand and forearm compared with other brachial plexus block

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Conflicts of Interest:

The authors report no conflicts of interest.

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This study was conducted with written informed consent from the study subjects. This report describes a prospective randomized clinical trial. The author states that the report includes every item in the CONSORT checklist for a prospective randomized clinical trial.

This was not an observational clinical study.

techniques. Block failures of the hand and forearm were due to inadequate cutaneous anesthesia of the ulnar (n = 27; 82%), median (n = 26; 78%), or radial (n = 22; 67%) distributions; the medial forearm (n = 25; 76%), and/or the lateral forearm (n = 14; 42%). Failure to achieve at least a 90% reduction in grip strength occurred in 16 subjects (48%).

Conclusions—This study did not find evidence to support the hypothesis that local anesthetic injected adjacent to the deepest brachial plexus roots/trunks reliably results in surgical anesthesia of the hand and forearm.

INTRODUCTION

Historically, the anterolateral interscalene nerve block—deposition of local anesthetic adjacent to the brachial plexus roots/trunks—has been used to provide surgical anesthesia and postoperative analgesia for procedures of the shoulder joint.^{1,2} The resulting block frequently failed to provide surgical anesthesia of the hand and forearm, even though the brachial plexus at this level included all of the axons of the upper extremity terminal nerves. One proposed explanation for this observation was that the brachial plexus was most commonly localized using electrical stimulation or induction of paresthesia(s) using the anterolateral approach, which presumably targeted the most superficial nerve(s)—providing innervation to the shoulder joint—but not the terminal nerves derived from the deeper (posterior) roots/trunks. With the introduction of ultrasound-guided peripheral nerve blocks, it is now relatively easy to target any desired portion of the brachial plexus. Indeed, there is an anatomic and clinical basis for the speculation that deposition of local anesthetic adjacent to the seventh cervical nerve root or inferior trunk will provide surgical anesthesia and analgesia for the entire upper extremity.^{3,4}

However, the accuracy of this conjecture remains uninvestigated, and therefore the overwhelmingly predominant peripheral nerve blocks provided for anesthesia/analgesia distal to the elbow are the axillary, infraclavicular, and supraclavicular approaches. Unfortunately, in some cases gaining and retaining proficiency in multiple peripheral nerve block techniques may prove challenging. Thus, a single peripheral nerve block technique that provides anesthesia/analgesia for any aspect of the upper extremity—regardless of surgical location—would be an attractive possibility, potentially changing many decades of practice.

We undertook this prospective cohort clinical trial to determine the proportion of cases in which deposition of local anesthetic using ultrasound guidance to target the deepest brachial plexus roots/trunks produces hand and forearm anesthesia within 30 minutes.

METHODS

The local Institutional Review Board (Human Research Protection Program, University California, San Diego, San Diego, California) approved the protocol and oversaw the study through data analysis. The investigation was prospectively registered on ClinicalTrials.gov prior to the beginning of enrollment (NCT01229683). Patients offered enrollment included adults (> 18 years) scheduled for at least moderately painful unilateral orthopedic surgery of the shoulder who desired and were approved for a single-injection mepivacaine interscalene brachial plexus nerve block and perineural catheter insertion. Exclusion criteria were contraindication to study medications or testing hand grip strength; known neuropathy of any etiology in the surgical extremity; pregnancy; incarceration; weight less than 40 kg; insulin-dependent diabetes mellitus (increased risk of subclinical neuropathy); and an inability to communicate with the investigators and hospital staff. All subjects provided written, informed consent prior to any study measurements or interventions.

Interscalene nerve block

All subjects had a peripheral intravenous catheter inserted in the nonsurgical upper extremity, standard American Society of Anesthesiologists-recommended external monitors applied, and oxygen administered by face mask (10 L/min). Intravenous midazolam (0–4 mg) and fentanyl (0–200 µg) were administered, while ensuring that patients remained responsive to verbal cues.

Subjects were placed in the lateral position with the surgical side up. After sterile preparation (Chloraprep One-Step, Medi-Flex Hospital Products, Inc, Overland Park, Kansas) and draping, the brachial plexus was identified in short axis by ultrasound between the anterior and middle scalene muscles using a high-frequency linear transducer (HFL38e for MicroMaxx, SonoSite, Bothell, Washington) at the root or trunk level.¹ The ultimate target for the needle tip was the point between the deepest and next-deepest brachial plexus roots/trunks (Figure 1). If these two structures were so close as to not have any space between them for the needle to enter, the transducer was moved in a distal direction until such a space was identified. The number of brachial plexus roots/trunks identified in this plane was then recorded. A local anesthetic skin wheal with lidocaine was injected to anesthetize the skin 1 to 2 cm posterior to the transducer. An insulated, 17-gauge, Tuohy-tip needle (Teleflex, Research Triangle Park, North Carolina) connected to a nerve stimulator was then inserted through the local anesthetic skin wheal and directed within the ultrasound visual plane toward the point between the deepest, and next-deepest brachial plexus root/trunk (between the middle and inferior trunks, or between the sixth and seventh cervical roots). After the needle tip passed through the anterior fascia of the middle scalene muscle, the nerve stimulator was turned on and the current increased from 0 mA until muscle motion was elicited (maximum of 5 mA). No attempt was made to alter the motor response by adjusting the needle.

Local anesthetic solution (30 mL of 1.5% mepivacaine with epinephrine, 2.5 µg/mL) was injected in divided doses with local anesthetic spread confirmed around the deepest-visualized neural elements (Figure 1). This was considered the end of the single-injection block and the time from the first Tuohy needle pass was recorded. It was also considered the beginning of the 30-minute observation period. The needle was then repositioned under ultrasound guidance so that the needle tip was placed between the most superficial, and next most superficial brachial plexus root/trunk, and an additional 10 mL of the same local anesthetic solution was injected. A 19 g flexible, non-stimulating catheter (FlexTipPlus, Teleflex Medical, Research Triangle Park, North Carolina) was then inserted 3 to 5 cm beyond the needle tip, and the needle removed over the catheter. Subjects who had an interscalene nerve block placed per protocol were retained in the study.

Outcome (end point) measurements

Measurements were performed prior to the interscalene block (baseline) before sedation was administered, and every 5 minutes following the end of the 30 mL injection for a total of 30 minutes or until the subject had to enter the operating room, whichever came first. The primary end point was the proportion of cases in which the interscalene nerve block resulted in a decrease in grip strength of at least 90% and hand and forearm anesthesia (tolerance to >50 mA of current in 5 terminal nerve distributions) within 30 minutes. Secondary end points included the number of nerves identified by ultrasound within the plane of block placement, minimum current evoking muscle response, degree of discomfort during block placement (measured on a 0–10 numeric rating scale), subject-reported paresthesia(s), and the time for block placement as measured from the first Tuohy needle insertion until the end of the 30 mL bolus of local anesthetic adjacent to the deep brachial plexus roots/trunks. A

successful interscalene block was defined as the inability to abduct at the shoulder joint within 30 minutes of local anesthetic deposition.⁵

Muscle strength—We evaluated muscle strength using a medical device specifically designed for this purpose (Jamar Plus+ Hand Dynamometer, Sammons Preston Company, Bolingbrook, Illinois).⁶ Subjects were asked to take 2 seconds to come to maximum effort, maintain this effort for 5 seconds, and then relax. The measurements immediately prior to interscalene nerve block placement were designated baseline measurements, and all subsequent measurements are expressed as a percentage of the pre-injection baseline.⁷ In addition, subjects were asked to abduct at the shoulder to assess motor block of the axillary nerve distribution.

Tolerance of transcutaneous electrical stimulation—We evaluated tolerance of transcutaneous electrical stimulation with the same quantitative procedure as the 1 described previously.^{8,9} Electrocardiogram pads were placed in 6 sensory nerve distributions of the upper extremity (Figure 2); and, the tolerance to cutaneous electrical current was obtained using a nerve stimulator (EzStim II, Model ES400; Life-Tech Inc, Stafford, Texas). The current was increased in 1 mA increments from 0 mA over approximately 10 seconds until subjects detected the electrical current (up to a maximum of 80 mA), at which time the current was recorded and the nerve stimulator turned off.

Statistical Analysis

The demonstrated success rate for ultrasound-guided infraclavicular, supraclavicular, and axillary nerve blocks is each approximately 95%.¹⁰ The sample size estimation of the current study was based on our primary hypothesis that a single-injection interscalene brachial plexus nerve block of the deep roots/trunks produces a similar rate of anesthesia of the hand and forearm to this known success rate of 95% for other brachial plexus block approaches. Analyzing 55 subjects provided greater than 80% power ($\alpha = 0.05$) to reject the null hypothesis that there is no difference between blocks if the proportion of successful anesthesia of the hand and forearm of subjects with an interscalene block is less than 85%. Success was defined for each subject as a decrease in grip strength of at least 90% from baseline, and tolerance to at least 50 mA of current in 5 terminal nerve distributions,⁹ as 50–60 mA is the current considered equivalent to a surgical incision.^{9,11,12} For the primary end point we included values measured at 30 minutes following block placement. A 1-sample proportion test was used to test the main hypothesis of this study. To assess change over time in grip strength, we applied a linear mixed-effects model to log transformed observations. The parameter estimates of the model fit are plotted with confidence intervals adjusted for the multiple time points.¹³ A post hoc analysis of the association between the number of nerve branches identified in the ultrasound plane and block success rate was performed using the Fisher's exact test.

RESULTS

Of 61 subjects enrolled in the study, one did not have a block placed due to a cancelled surgery, 4 did not have a block placed per protocol, 1 did not have post-block data collected (included in the demographic profile but not analyses), and the remaining 55 were included in the analyses (Table 1). All of these 55 interscalene blocks resulted in an inability to abduct at the shoulder joint after 20 minutes or less, and were therefore considered successful, per protocol.

Primary end point

Thirty-three subjects had measurements at 30 minutes following local anesthetic deposition, with the remainder sent to the operating room prior to this time point. Of these 33 subjects, only 5 (15%) had a surgical block of the hand and forearm ($P < 0.0001$; 95% CI: 6–33%; Figure 3) as defined by this study (grip strength reduction of $> 90\%$ and tolerance to 50 mA of cutaneous current in 5 terminal nerve distributions; Figure 4). We therefore reject the null hypothesis that the interscalene block as performed in this study provides equivalent anesthesia to the hand and forearm as compared with the published rate of 95% for other ultrasound-guided brachial plexus blocks. In contrast, all subjects included in the primary end point analysis were unable to abduct the shoulder within 30 minutes of block placement, indicating accurate local anesthetic deposition adjacent to the brachial plexus.

Secondary end points

A post hoc analysis of subjects with measurements available at 30 minutes following local anesthetic injection ($n = 33$) found that there was an association between the number of brachial plexus roots/trunks visualized (3–4 vs 5) and block success rate (Table 2). The mean percent change from baseline in grip strength was significantly different from zero ($P < 0.001$) at all 6 time points (Figure 5).

DISCUSSION

To our knowledge, this prospective cohort clinical trial is the first investigation to objectively evaluate the proportion of cases in which deposition of local anesthetic adjacent to the deepest brachial plexus roots/trunks produces hand and forearm anesthesia. Only 15% of subjects evaluated 30 minutes after local anesthetic injection had a surgical-quality block in 5 terminal nerve distributions of the hand and forearm along with a reduction of grip strength of at least 90% ($P < 0.0001$). Therefore, with a 95% confidence interval of 6% to 33%, we can say that there is 95% probability that the interval 6% to 33% includes the population (true) success rate.

Conventional wisdom has long dictated that a single-injection peripheral nerve block of the brachial plexus roots/trunks—what is typically described as an “interscalene” block—provides anesthesia for shoulder surgery, but frequently spares the terminal nerves innervating the hand and forearm, even with an ultrasound-guided posterior approach.¹ However, since the interscalene approach is used nearly exclusively for shoulder surgery we, and others,¹⁴ have targeted the fifth and sixth cervical nerve roots or superior trunk of the brachial plexus since the nerves innervating the shoulder are derived from these structures. However, another investigator has proposed that the posterior approach is beneficial to specifically target certain nerve roots depending on surgical anesthesia requirements.³ This conviction has been supported by the findings of another investigator who, in an effort to reduce phrenic involvement with a posterior approach, found that depositing local anesthetic adjacent to the deepest-visualized roots/trunks resulted in a block that favored these dermatomes more than the traditional anterolateral interscalene approach.⁴ Thus, we were cautiously optimistic that specifically targeting the seventh cervical root or inferior trunk would result in reliable anesthesia of the hand and forearm. Unfortunately, the results of our prospective investigation do not support the deposition of local anesthetic at the root/trunk level to provide hand and forearm anesthesia when other approaches targeting the brachial plexus at or distal to the cords have a dramatically higher rate of success.⁸

It is important to note that the posterior approach previously described by our colleague and purported to adequately block the hand and forearm (described as a “cervical paravertebral block”) is “a “blind” technique in which the brachial plexus roots are specifically targeted

by nerve stimulation.³ It is therefore noteworthy that we found a 40% success rate of achieving a surgical block of the hand and forearm when 5 brachial plexus elements—presumably the brachial plexus roots, including the eighth cervical and first thoracic roots—were identified in the ultrasound plane, versus a 4% success rate when 3–4 elements—presumably the brachial plexus trunks or transition zone—were identified ($P=0.0214$; Table 2). Although it is possible that the brachial plexus divisions—as opposed to roots—were visualized, resulting in a supraclavicular block, we believe this to be highly improbable since the portion of the brachial plexus targeted was the most proximal visible in the interscalene groove.

By any reasonable clinical standard, a 40% success rate remains unacceptably low for hand and forearm anesthesia given alternative ultrasound-guided brachial plexus approaches have reported rates of approximately 95%.¹⁰ The current results do suggest that the common ultrasound-guided approach that we used/described will not result in an acceptable success rate, regardless of the brachial plexus level targeted.

Inhibiting shoulder abduction—enabled primarily by the axillary nerve—was our indication of successfully depositing local anesthetic adjacent to the brachial plexus.⁵ While the posterior approach is championed as favoring sensory vs. motor block,³ we used abduction as the criteria indicating successful local anesthetic adjacent to the brachial plexus as opposed to a sensory endpoint because of the potential for variability in cutaneous innervation of the shoulder, with possible contributions from not only the axillary, but supraclavicular nerves.^{15–17} Indeed, we observed that all patients included in the primary end point analysis were unable to abduct, but 16% failed to exhibit surgical anesthesia over the shoulder.

Our previous experience suggests that when the needle tip penetrates the anterior fascia of the middle scalene muscle, the risk of a paresthesia is increased—not surprisingly—if the needle is pointed directly at a nerve. Due to the anatomic variability of the brachial plexus among subjects, the number—and presumably brachial plexus level—of visualized neural elements was variable. Even with care to never direct the needle towards a nerve branch, 25% of subjects experienced a paresthesia. The clinical ramifications of this finding remain undetermined.¹⁸

Study Limitations

As alluded to previously, the results of this investigation pertain specifically to the techniques used in this study—other approaches would have most likely altered our findings. In addition, the level of the brachial plexus intercepted by the Tuohy needle was presumably variable among subjects given that 3 to 5 neural elements were identified within the ultrasound plane. We did not attempt to identify which specific neural elements were being visualized in the interscalene groove; a more targeted injection may have provided more information, but we do not believe it would have altered the results as it is considered acceptable to deposit local anesthetic adjacent to either the brachial plexus roots or trunks during traditional interscalene blocks provided for surgical procedures of the shoulder. Our study technique resulted in a 100% success rate in inhibiting shoulder abduction; and, while there was a 16% failure rate in providing surgical anesthesia over the shoulder (presumably from supraclavicular nerves and a failure of the second 10 mL injection to spread to the superficial cervical plexus), all subjects exhibited an increase in tolerance to cutaneous current, suggesting the sensory fibers of the axillary nerve were effected.

Lastly, of 55 subjects who received an interscalene block per study protocol, 22 had to depart for the operating room prior to the 30-minute time point, on which the primary end point was based (in contrast, all 55 subjects were included in the secondary end points).

However, since the deciding factor on which blocks were included in the primary end point was independent of block success—but, rather, on when the operating room was ready for the subject—this does not constitute a confounding factor, and the results are no less valid. The power of the study to reject the null hypothesis is decreased with the smaller number of subjects, but the success rate for hand and forearm anesthesia using the interscalene block was so low, that adequate power was retained with the 33 subjects included in the primary analysis ($P < 0.0001$; 95% CI: 6–33%).

In conclusion, this investigation did not find evidence to support the hypothesis that local anesthetic injected adjacent to the deepest brachial plexus roots/trunks using a posterior, ultrasound-guided, needle in-plane approach reliably results in surgical anesthesia of the hand and forearm.

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Figure 1. Ultrasound image of interscalene groove with needle position (arrow) and local anesthetic spread (asterisks) around the deepest-visualized neural element (C7 or Inferior Trunk). SCM: sternocleidomastoid muscle; ASM: anterior scalene muscle; MSM: middle scalene muscle; N: nerves of the brachial plexus.

Figure 2.
Electrode placement for sensory testing.

Figure 3.

Sensory (as measured by tolerance to cutaneous electrical current) and motor block (as measured by grip strength) 30 minutes following local anesthetic injection. Values presented for the sensory nerves indicate the proportion of subjects who tolerated at least 50 mA of electrical current for each of five terminal nerves of the hand and forearm, as well as the skin over the inferior region of the deltoid muscle approximating the sensory distribution of the axillary nerve.

Figure 4.

The progression of sensory (as measured by tolerance to cutaneous electrical current) and motor block (as measured by grip strength) throughout the study period. All subjects (n = 55) with an interscalene block placed per study protocol are included.

Figure 5. Mixed-effects model results. The mean percent change of grip strength from baseline was significantly different from zero ($P < 0.001$) at all six time points. The P values and confidence intervals have been adjusted for multiple comparisons.

Table 1

Subject and block characteristics, summarized according to inclusion or exclusion in the primary analysis. The table includes *P* values from two-sample t-tests and Fisher's exact tests.

	Excluded (N=23)	Included (N=33)	Overall (N = 56)	<i>P</i> value
Age (yr)	51 (17)	51 (16)	51 (16)	0.917
Sex (female/male)	13 (57%)	8 (24%)	21 (36%)	0.024
Height (cm)	170 (10)	174 (10)	173 (10)	0.150
Weight (kg)	83 (16)	79 (13)	81 (14)	0.280
Body mass index (kg/m ²)	28.8 (5.4)	26.0 (3.9)	27.0 (5.0)	0.040
Block placement (min)	4.4 (1.9)	3.7 (1.5)	4.0 (1.7)	0.206
Fentanyl (μg)	100 (43.6)	103 (31)	102 (37)	0.780
Midazolam (mg)	1.8 (0.9)	2.1 (0.6)	1.9 (0.7)	0.178
Nerves visualized within ultrasound plane (#)				0.675
3	10 (43%)	10 (30%)	20 (36%)	
4	10 (43%)	13 (39%)	23 (41%)	
5	3 (13%)	10 (30%)	13 (24%)	
Patient-identified paresthesia (#)	6 (27%)	8 (25%)	14 (25%)	0.402
Patient-described <i>worst</i> discomfort (NRS)	2.3 (3.2)	1.6 (1.9)	1.8 (2.5)	0.119
Patient-described <i>average</i> discomfort (NRS)	1.5 (2.4)	0.5 (1.0)	0.9 (1.7)	0.126
Evoked muscle response at a minimum current of <0.5 mA (#)	7 (33%)	11 (34%)	18 (33%)	0.272
Evoked muscle response at a minimum current of 0.5–1.0 mA (#)	12 (57%)	13 (41%)	25 (45%)	0.282
Evoked muscle response at a minimum current of <1.0–5.0 mA (#)	2 (10%)	8 (25%)	9 (16%)	0.562
No evoked muscle response at 5.0 mA (#)	2 (9%)	1 (3%)	3 (5%)	0.402
Evoked muscle responses (#)				
Shoulder	14 (22%)	25 (40%)	39 (71%)	
Elbow Flexion	7 (13%)	2 (4%)	9 (16%)	
Elbow Extension	4 (7%)	2 (4%)	6 (11%)	
Wrist/Hand Flexion	2 (4%)	3 (5%)	5 (9%)	
Wrist/Hand Extension	0	3 (5%)	3 (5%)	
Supination	0	1 (2%)	1 (2%)	

Values are reported as mean (SD) or number of subjects (%)

NRS: Numeric Rating Scale

Table 2

Brachial plexus branches visualized within the ultrasound plane and hand/forearm block success rate (includes subjects with measurements available at 30 minutes following local anesthetic injection who were therefore included within the primary analysis).

Branches Visualized	Successful Block	Unsuccessful Block	P Value
3-4	1 (4%)	22 (96%)	0.0214
5	4 (40%)	6 (60%)	
Totals:	5 (15%)	28 (85%)	

Values are reported as number of subjects (%)