ANESTHESIOLOGY

Superior Trunk Block

A Phrenic-sparing Alternative to the Interscalene Block: A Randomized Controlled Trial

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EDITOR'S PERSPECTIVE

What We Already Know about This Topic

- Interscalene nerve block is commonly used for shoulder surgery for anesthesia and postoperative analgesia
- Unfortunately, interscalene blocks commonly result in hemidiaphragmatic paralysis

What This Article Tells Us That Is New

- When interscalene block was compared with superior trunk block, less frequent hemidiaphragmatic paralysis was seen in the superior trunk block group
- Superior trunk block was noninferior to interscalene block in terms of worst pain scores in the recovery room, and superior trunk block patients were more satisfied

ABSTRACT

Background: Interscalene nerve blockade remains one of the most commonly used anesthetic and analgesic approaches for shoulder surgery. The high incidence of hemidiaphragmatic paralysis associated with the block, however, precludes its use among patients with compromised pulmonary function. To address this issue, recent studies have investigated phrenic-sparing alternatives that provide analgesia. None, however, have been able to reliably demonstrate surgical anesthesia without significant risk for hemidiaphragmatic paralysis. The utility of the superior trunk block has yet to be studied. The hypothesis was that compared with the interscalene block, the superior trunk block will provide noninferior surgical anesthesia and analgesia while sparing the phrenic nerve.

Methods: This randomized controlled trial included 126 patients undergoing arthroscopic ambulatory shoulder surgery. Patients either received a superior trunk block (n = 63) or an interscalene block (n = 63). The primary outcomes were the incidence of hemidiaphragmatic paralysis and worst pain score in the recovery room. Ultrasound was used to assess for hemidiaphragmatic paralysis. Secondary outcomes included noninvasively measured parameters of respiratory function, opioid consumption, handgrip strength, adverse effects, and patient satisfaction.

Results: The superior trunk group had a significantly lower incidence of hemidiaphragmatic paralysis compared with the interscalene group (3 of 62 [4.8%] *vs.* 45 of 63 [71.4%]; $P < 0.001$, adjusted odds ratio 0.02 [95% CI, 0.01, 0.07]), whereas the worst pain scores in the recovery room were noninferior (0 [0, 2] *vs.* 0 [0, 3]; $P = 0.951$). The superior trunk group were more satisfied, had unaffected respiratory parameters, and had a lower incidence of hoarseness. No difference in handgrip strength or opioid consumption were detected. Superior trunk block was associated with lower worst pain scores on postoperative day 1.

Conclusions: Compared with the interscalene block, the superior trunk block provides noninferior surgical anesthesia while preserving diaphragmatic function. The superior trunk block may therefore be considered an alternative to traditional interscalene block for shoulder surgery.

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Arthroscopic shoulder surgery is associated with significant pain.[1] Interscalene nerve block remains the most commonly used peripheral nerve block for shoulder surgery.[2,3] It can be used as the sole surgical anesthetic with significant analgesic benefit postoperatively, thus expediting discharge and lowering opioid consumption.[3] Its validated effectiveness makes it an attractive component of any opioid-sparing multimodal regimen. However, its benefits are offset by high rates of associated hemidiaphragmatic paralysis *via* inadvertent blockade of the phrenic nerve. This side effect frequently precludes its use among patients with significant pulmonary disease. Hemidiaphragmatic paralysis has been reported to occur in up to 100% of interscalene recipients.[4,5] This adverse effect has potentially devastating consequences and has therefore led to recent interest in investigating potential phrenic nerve–sparing nerve blocks.

Attempting to spare the phrenic nerve, clinicians first investigated variations of the interscalene block, targeting different locations (such as posterior to the C5 root), using various local anesthetic concentrations as well as different volumes. Studies using volumes as low as 5 ml have decreased the incidence of hemidiaphragmatic paralysis to

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27 to 45%.[6,7] Despite this significant reduction, the risk of blocking the phrenic nerve with interscalene block remains unacceptably high to be used with confidence in a respiratory compromised patient. Maalouf *et al.*[8] performed low-volume interscalene blocks using 20 ml and noted a 19.1% decrease in the negative inspiratory force, translating into a potentially clinically significant reduction in a vulnerable patient.

Supraclavicular brachial plexus blocks by virtue of their more distal location away from the phrenic nerve are suggested to reduce the incidence of hemidiaphragmatic paralysis.[9,10] A study done by Renes *et al.*[11] demonstrated that an ultrasound-guided posterior–lateral supraclavicular block using 20 ml resulted in no hemidiaphragmatic paralysis in 30 patients. However, this study was performed on patients undergoing elbow and hand surgery, preventing conclusions to be drawn for shoulder surgery patients. By limiting the volume for the supraclavicular block, it is likely that the suprascapular nerve is spared with inadequate proximal spread. This may therefore lead to inadequate analgesia, because the suprascapular nerve provides 70% of the innervation of the shoulder joint and arises from the superior trunk.[12] Therefore, for supraclavicular nerve blocks to provide surgical anesthesia for shoulder surgery, enough volume must be administered to spread to the suprascapular nerve; problematically, hemidiaphragmatic paralysis has been shown to occur with volumes at and more than 20 ml.[10,13]

The ideal shoulder block would be as effective as an interscalene block, providing surgical anesthesia and sparing the diaphragm and hand, with minimizing adverse effects such as dyspnea and hoarseness. In this context, a recently published case study illustrated the use of a refined ultrasound-guided variation of the interscalene block: the superior trunk block.[14] The superior trunk block was performed on a pulmonary-compromised patient using a low volume of 12 ml, and subsequently a lack of hemidiaphragmatic paralysis was confirmed by ultrasound. Since, a modest number of reviews and anatomical confirmation literature has become available.[13,15–17] However, there are no randomized controlled trials comparing superior trunk block and interscalene block effects on the development of hemidiaphragmatic paralysis. Therefore, the purpose of this study is to investigate whether a low-dose superior trunk block is as effective in providing analgesia for shoulder surgery as an interscalene block, while minimizing the occurrence of hemidiaphragmatic paralysis. We hypothesized that (1) analgesia with a superior trunk block would be noninferior compared with patients receiving an interscalene block and (2) the incidence of hemidiaphragmatic paralysis would be significantly lower with the superior trunk block.

Materials and Methods

The Institutional Research Board (Hospital for Special Surgery, New York, New York) approved this study, which was conducted from September 2017 to August 2018. The study was registered with ClinicalTrials.gov (NCT03272139) on September 5, 2017. A team of regional anesthesiologists considered experts by their peers in superior trunk block and interscalene block techniques provided or supervised anesthesia for all enrolled patients. A total of 126 patients scheduled for elective ambulatory arthroscopic shoulder surgery participated in the trial. Research assistants screened patients undergoing ambulatory shoulder arthroscopic surgeries. After confirming eligibility with the investigator anesthesiologists, patients were approached in the holding area by one of the investigators, who explained the rationale for the study. The investigators and research assistants obtained written informed consent and enrolled the participants. A computer-generated, 1:1 ratio randomization schedule with blocks of sizes 4 and 6 was created by a statistician not otherwise involved in the study. Immediately after patient arrival to the operating room, the investigator anesthesiologist assigned to the case opened a sequentially numbered sealed opaque envelope containing assignment to either the superior trunk or the interscalene group.

We included patients if they were aged 18 to 80, had an American Society of Anesthesiologists physical status I to III, were English-speaking, and were able to follow the study protocol. Patients were excluded if they had severe pulmonary disease, allergy to one of the study medications, chronically used gabapentin or pregabalin (regular use of longer than 3 months), chronic opioid use (taking opioids longer than 3 months or more than 5 mg/day oral morphine equivalents for 1 month), preexisting neuropathy of the operative limb, herniated cervical disc, cervical myelopathy, planned use of general anesthesia, or body mass index more than 35 kg/m^2.

The primary outcomes for which the study was powered were the incidence of hemidiaphragmatic paralysis and worst numerical rating scale pain scores at rest in the postanesthesia care unit (PACU). Secondary outcomes included changes in tidal volume and minute ventilation measured by a noninvasive respiratory monitor (ExSpiron 1xi; Respiratory Motion, Inc., USA), patient satisfaction, block duration, numerical rating scale pain scores on postoperative days 1 to 2, opioid consumption, handgrip, and complications.

Only the operating room anesthesiologists performing the nerve blocks were not blinded to group assignment. Surgeons, nurses, research assistants, and patients were all blinded in respect to group assignment. The anesthesiologist performing the block opened the sealed enveloped in the operating room after the patient received sedation, ensuring the patient remained blinded to the group assigned. In the recovery room, patient pain scores were assessed by blinded research assistants. Blinded anesthesiologists not otherwise involved in the care of the patient assessed hemidiaphragmatic motion *via* ultrasound. Recovery room nurses who administered opioids were also blinded. All patients were discharged and went home on the day of surgery with a brace. At home, patient follow-up was performed by research assistants *via* telephone interviews. The study

was conducted in accordance to the original protocol, and no changes were made to the eligibility criteria during the trial. The trial was done at a single institution, the Hospital for Special Surgery (New York, New York). No interim analysis was performed, and the study was not stopped early. Full trial protocol is available upon request.

Baseline Measurements

In the holding area, the research assistant collected demographic data and assessed patient handgrip strength. Using a dynamometer (Smedley digital hand dynamometer; Fabrication Enterprises Inc., USA), grip strength was recorded as per maximum voluntary isometric contraction. Patients performed this task three times, and an average was calculated. A noninvasive respiratory monitor (ExSpiron 1xi) was attached to the patient in the holding area and respiratory parameters (tidal volume and respiratory rate) were recorded for 15 to 30 min. The anesthesiologist assessed diaphragmatic movement in the holding area using a c60 curvilinear probe (SonoSite Xporte, USA). It is our institutional standard to have the surgical physician assistant perform a sensory (*e.g.*, intact sensation to light touch) and motor strength exam (scale from 0 to 5) on the operative extremity in the holding area before surgery. Any patient with an abnormal exam was not eligible for the study and subsequently not approached.

Nerve Blocks

All blocks were placed under sterile conditions in the operating room with sedation (intravenous midazolam 2 to 5 mg and fentanyl up to 100 mcg), titrated to a Ramsey Sedation Scale score of 2 to 3. The interscalene block was performed using a high-frequency linear ultrasound transducer (SonoSite M-Turbo, USA). After identifying the cervical roots and interscalene muscles, a 22-gauge 2 3/8-inch Chiba needle (Havel's Incorporated, USA) was inserted, lateral to medial, with in-plane technique into the interscalene groove. The tip of the needle was placed in between C5 and C6, and 15 ml of 0.5% bupivacaine was deposited.

For the superior trunk block, after identifying the cervical roots and scalene muscles, the probe was moved distally until the suprascapular nerve branches off the superior trunk were seen. The targeted level of insertion for the injection was immediately before the branching off point of the suprascapular nerve. A 22-gauge 2 3/8-inch Chiba needle (Havel's Inc.) was inserted, lateral to medial, using in-plane technique. The tip of the needle was placed posterior/inferior to the trunk, and 10 ml were injected. The needle was then redirected anteriorly/superiorly to the trunk, while remaining laterally to the trunk, and 5 ml were injected anteriorly (fig. 1; see also the video in the Supplemental Digital Content, http://links.lww.com/ALN/B986).

After 15 to 20 min of the nerve block, each patient had a sensory and motor examination by the anesthesiologist to ensure blockade of the C5 and C6 nerve roots. Each patient was assessed for numbness in the hand/arm and weakness during shoulder abduction. In the event of an inadequate or failed blockade, general anesthesia or supplemental blockade was to be done before surgical incision. Each anesthesia record was audited by a blinded research assistant who was not involved in patient enrollment or postoperative assessment. They assessed for anesthetic deviations (*e.g.*, conversion to general anesthesia, rescue blocks performed either intraoperatively or postoperatively), and none were found in the study. The noninvasive respiratory monitor was immediately attached to the patient after the nerve block was placed and measured respiratory parameters for 60 min intraoperatively.

Intraoperative Management

Intravenous sedation was provided with propofol and titrated at the discretion of the anesthesiologist to maintain sedation with adequate respirations. Failed blocks were identified by conversion to general anesthesia, fentanyl requirements in excess of 100 mcg, or any amount of ketamine or hydromorphone to supplement analgesia. All patients received ketorolac (30 mg, if more than 65 yr of age, then 15 mg), ondansetron (4 mg), and dexamethasone (4 mg) intravenously. The surgeons did not inject additional local anesthetic at the surgical sites.

Postoperative Respiratory Assessment and Diaphragmatic Movement

Respiratory parameters were recorded at baseline in the holding area, intraoperatively and in the recovery room, using a noninvasive monitor (ExSpiron 1xi). The average minute ventilation, respiratory rate, and tidal volume of each patient were recorded by the blinded research assistant.

Although forced vital capacity has been used as an indirect marker for diaphragmatic weakness,[18] we used ultrasonography to directly measure changes in diaphragmatic movements. Ultrasonography allows for an accurate, reproducible, noninvasive, portable, and radiation-free assessment of diaphragm function.[19] After reviewing recent studies on ultrasound techniques that demonstrated high interobserver reliability and low incidence of failure to visualize hemidiaphragmatic motion (as low as 0.71%),[20] we were able to identify hemidiaphragmatic motion in all patients enrolled in the study, directly identifying complete, partial, and no paresis.

Visualization of the left-sided hemidiaphragmatic motion is more challenging because of the smaller window of the spleen, especially in patients with high body mass indexes. For this reason, we made the body mass index more than 35 an exclusion criterium and learned to optimize scans by placing patient in the supine position, using a c60 curvilinear probe at different locations. After reviewing the literature,[19–22] we developed a stepwise approach for left-sided scans that were difficult to assess. First, in the supine position, the transducer was placed in the anterior

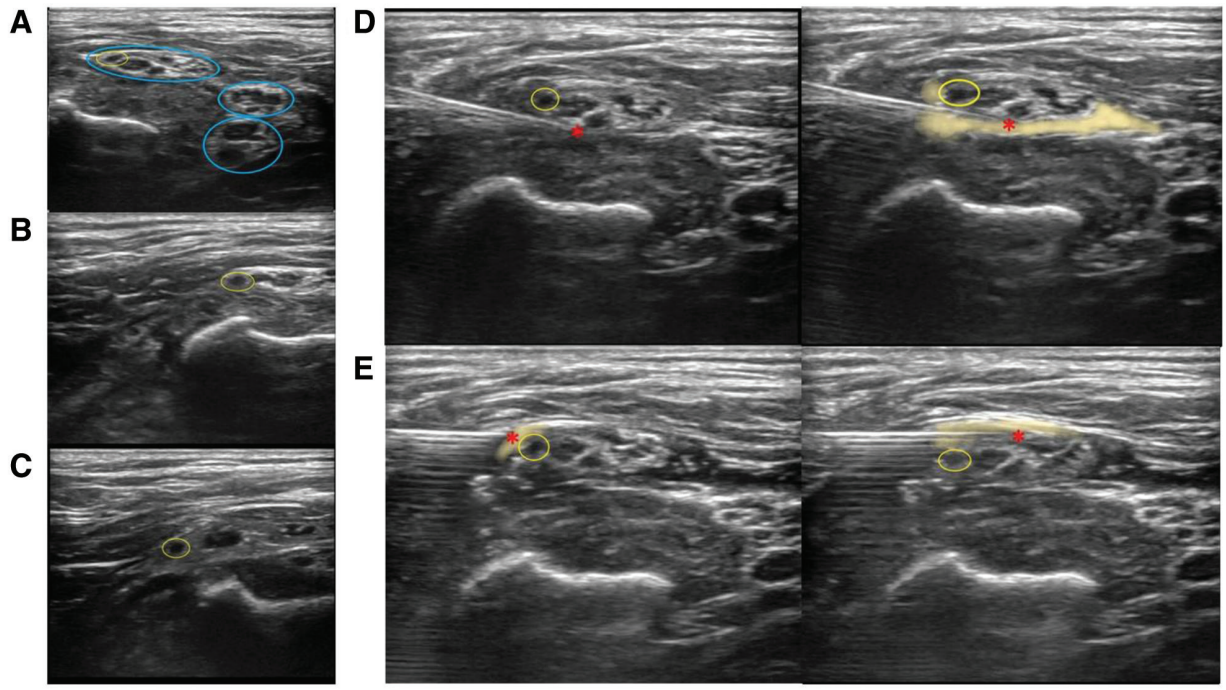

Fig. 1. Ultrasonography of superior trunk block. *Yellow ovals* mark suprascapular nerve. *Red asterisks* correspond to needle tip. (*A*) Superior trunk, middle trunk, and inferior trunk are marked with *blue ovals*. (*B*, *C*) As we scan distally, the suprascapular nerve is branching off the superior trunk (*B*) and diving under the omohyoid (inferior belly, *C*). (*D*) Needle is placed posteriorly to the superior trunk as local anesthesia is injected (local anesthetic spread in *yellow highlight*). (*E*) Needle is repositioned anteriorly and laterally as local is injected (see also the video in the Supplemental Digital Content, http://links.lww.com/ALN/B986).

subcostal region between the midclavicular and anterior axillary lines, angled so the beam reaches the posterior part of the diaphragm. Second, a more coronal intercostal approach paralleling the ribs was used. By using these methods and excluding body mass indexes more than 35, we were able to visualize the diaphragm in all patients, both left and right, and successfully assessed motion and diaphragmatic excursions. We did have obscuration of the hemidiaphragm on excursions on the left side as the lung displaces downward. During these situations, we did an intercostal approach using a higher frequency linear array transducer in the anterior axillary line, identifying the zone of apposition between the diaphragm and parietal pleura and marking the movement (excursion) during deep inspiration. The location was marked so the blinded anesthesiologists could repeat the placement used on the original scan.

A blinded anesthesiologist performed the ultrasound assessment of diaphragmatic function within 1 h of the patient's arrival in the recovery room. Diaphragmatic excursion with deep inspiration was measured. We defined the incidence of hemidiaphragmatic paralysis to be a decrease in diaphragmatic movement that (1) was greater than 75% of baseline or (2) showed paradoxical movement. We did note findings as partial, complete, and none, and defined them as follows: "partial" equated to 25 to 75% decrease from baseline, "complete" was defined as more than 75% decrease from baseline or paradoxical movement, and "none" was defined as changes between 0 and 25% from baseline. All ultrasound evaluations were confirmed by a second blinded anesthesiologists to ensure quality in the assessment. In the event that the second confirmation conflicted with the first, a third anesthesiologist performed an additional, independent ultrasound evaluation.

Adverse Effects

Patients were assessed for the presence of dyspnea, hiccups, hoarseness, and Horner's syndrome in the recovery room. Neuropraxia was assessed at 1 week and defined as persistent numbness, tingling, and/or weakness in the operative extremity.

Motor Function

Within 1 h of arrival in the recovery room, all patients were assessed for hand strength using a dynamometer. Three trials were recorded and averaged. Research assistants also tabulated the incidence of complete motor block of the hand.

Numerical Rating Scale Pain and Block Duration

Numerical rating scale pain scores at rest were measured every 30 min until discharged from the recovery room. The worst

numerical rating scale pain scores were defined as the highest pain score recorded. A blinded research assistant conducted a scripted phone interview with the patients on postoperative days 1 and 2, assessing pain scores at rest and movement (abduction of arm), time of first pain medication for shoulder pain at home, time of complete block resolution, and when normal sensation returned in the distribution of the block.

Statistical Analysis

This study was designed to assess the joint hypothesis of superiority of superior trunk block compared with interscalene block based on incidence of hemidiaphragmatic paralysis and noninferiority as measured by worst numerical rating scale pain score in the recovery room. A pilot study comparing the incidence of hemidiaphragmatic paralysis between the interscalene block and supraclavicular nerve block revealed an incidence of 76% and 40.6%, respectively (unpublished data). Because the superior trunk block would have a lower incidence of hemidiaphragmatic paralysis than the supraclavicular nerve block, we expected at least a 35% reduction in the incidence of hemidiaphragmatic paralysis. After reviewing the literature comparing interscalene nerve block with supraclavicular nerve blocks with reported statistically significant differences of 19 to 29.5%,[10,23] our research group decided on a minimum threshold difference of 35% to be clinically meaningful. A difference in worst numerical rating scale score greater than 1.6 points with a SD of 2.9 was considered meaningful and was established as the noninferiority margin.[24,25] Accounting for a potential 20% attrition rate, evaluating the noninferiority hypothesis required a larger sample size of 126 compared with 80 for the superiority hypothesis. Thus, 126 was deemed an acceptable sample size to achieve approximately 80% power at an α level of 0.025 for both portions of the joint hypothesis.

All 126 of the enrolled patients were included in analyses. A descriptive summary of baseline characteristics was conducted, stratified by treatment group, with categorical variables reported as frequencies and continuous as median (interquartile range [IQR]) to account for nonnormal distributions. Standardized differences were reported for all baseline demographic information to determine the effectiveness of randomization. A standardized difference greater than 0.1 indicates a meaningful difference in the distribution of covariates between the two treatment groups.[26]

Incidence of hemidiaphragmatic paralysis was compared between the two blocks using a two-tailed Fisher's exact test. A multivariable logistic regression model was used as a secondary approach to evaluate the difference in incidence of hemidiaphragmatic paralysis adjusting for potential confounders (age, sex, ethnicity, race, body mass index, American Society of Anesthesiologists class, laterality, and length of surgery). The data for worst numerical rating scale pain in the recovery room was heavily skewed toward zero, limiting the interpretability of traditional noninferiority testing methods using two one-sided tests (97.5% CI using the Hodges–Lehmann method was [0.0, 0.0]). To circumvent this issue, we reported incidence of non-zero numerical rating scale pain across the two treatment groups, assessed using a chi-square test. After applying a Bonferroni correction to the overall α of 0.05 to adjust for our analysis of two primary outcomes, a P value less than 0.025 was considered the cutoff for statistical significance.

Continuous outcomes (*e.g.*, numerical rating scale pain score, PACU length of stay, patient satisfaction, block duration, and opioid consumption) were compared between the superior trunk and interscalene groups using two-sample independent t tests or Mann–Whitney Wilcoxon rank tests for outcomes that were not normally distributed. Categorical outcomes were compared using either chi-square or Fisher's exact tests. Continuous and categorical outcomes measured at multiple time points (*e.g.*, handgrip strength and respiratory function) were analyzed using a generalized estimating equations approach clustering by patient with an exchangeable covariance structure and an interaction between treatment group and time point. For all secondary outcomes, results with $P < 0.05$ were considered statistically significant. All analyses were conducted using SAS version 9.4 (SAS Institute, USA).

Results

A Consolidated Standards of Reporting Trials (CONSORT) flow diagram of patient selection and dropout is presented in figure 2. In total, 126 patients were enrolled in the study, 63 in each group. One patient refused to participate in the data collection process in the recovery room. Baseline and intraoperative data were available for this patient and included in the analysis. All other patients completed the primary outcome assessments.

Baseline Measurements

There were no significant differences in baseline demographic characteristics between superior trunk and interscalene groups (table 1). We standardized our study population to be therapeutic arthroscopic surgeries, excluding diagnostic surgeries. The open surgeries we enrolled were all unanticipated conversions from arthroscopy: two biceps tenotomy and a shoulder arthrotomy for open stabilization. We included all enrolled patients for intention-to-treat analysis. At our institution, shoulder arthroscopy is routinely managed solely under regional anesthesia with sedation. The reason we distinguished rotator cuff from non–rotator cuff arthroscopic surgeries is because the former has been reported to be more painful in the orthopedic literature.[27] We wanted to make sure one group did not have more "painful" surgeries that may confound the results. Moreover, most of the surgeries were performed in less than 120 min, decreasing the chance of extravasation of fluid in the chest wall, which would confound pain scores and dyspnea. As we demonstrated in our baseline demographics, there was no difference in surgical type and duration. In the study, no patients were found to have an inadequate block either intraoperatively or postoperatively.

Primary Outcomes: Hemidiaphragmatic Paralysis and Worst Numerical Rating Scale Pain

The incidence of hemidiaphragmatic paralysis was significantly lower in the superior trunk group than in the interscalene group (3 of 62 [4.8%] *vs.* 45 of 63 [71.4%]; $P < 0.001$). Upon adjusting for patient demographics and procedure attributes, the odds of hemidiaphragmatic paralysis in the superior trunk group remained significantly lower than interscalene group (odds ratio, 0.02; 95% CI, 0.01, 0.07). The interscalene group had 11 of 63 (17.5%) patients with partial paresis and 6 of 63 (9.5%) with no paresis. The

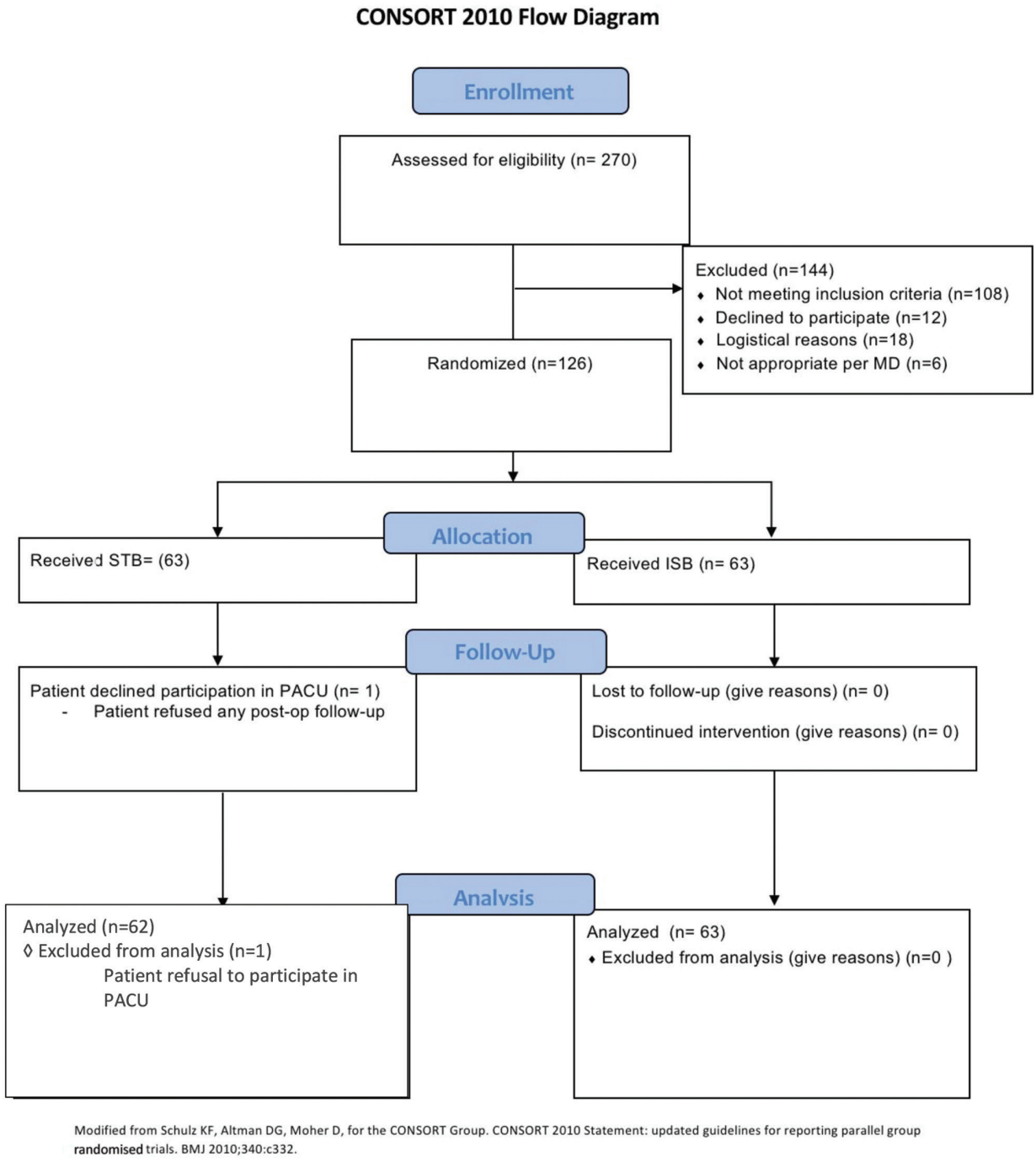

Fig. 2. Consolidated Standards of Reporting Trials (CONSORT) diagram of patient flow through the study. ISB, interscalene block; MD, medical doctor; PACU, postanesthesia care unit; STB, superior trunk block.

Table 1. Patient Characteristics and Demographics

Distribution of Baseline Covariates across Treatment Groups	Superior Trunk Block (n = 63)	Interscalene Block (n = 63)	STD
Age, yr (median [IQR])	51.5 [37.0, 60.0]	50.0 [38.0, 59.0]	0.154
BMI (median [IQR])	27.2 [24.8, 29.8]	26.8 [24.4, 29.6]	0.013
Length of surgery, min (median [IQR])	49.0 [32.0, 62.0]	46.0 [35.0, 66.0]	0.027
Sex, %			0.181
Male	49 (77.8)	44 (69.8)	
Female	14 (22.2)	19 (30.2)	
Ethnicity, %			0.001
Hispanic or Latino	4 (6.4)	4 (6.4)	
Not Hispanic or Latino	58 (92.1)	58 (92.1)	
Unknown/unavailable	1 (1.6)	1 (1.6)	
Race, %			0.32
Asian	0 (0)	2 (3.2)	
Black/African American	4 (6.4)	4 (6.4)	
Native Hawaiian/other Pacific Islander	1 (1.6)	0 (0)	
White	54 (85.7)	52 (82.5)	
Unknown/unavailable	4 (6.4)	5 (7.9)	
ASA class, %			0.31
1	10 (15.9)	18 (28.6)	
2	52 (82.5)	44 (71.0)	
3	1 (1.6)	1 (1.6)	
Laterality, %			0.162
Left	23 (36.5)	28 (44.4)	
Right	40 (63.5)	35 (55.6)	
Type of surgery, %			
RCR	30 (47.6)	31 (49.2)	0.186
Non-RCR	32 (50.8)	30 (47.6)	
Open tenotomy	1 (1.6)	1 (1.6)	
Open arthrotomy	0 (0)	1 (1.6)	
Baseline NRS (median [IQR])	2.0 [0, 3.0]	2.0 [0, 3.0]	0.296
Baseline diaphragmatic excursion, cm (median [IQR])	5 [4, 6]	5 [4, 6]	
Baseline Oxygen saturation, % (median [IQR])	98 [96, 99]	98 [96, 99]	

ASA, American Society of Anesthesiologists; BMI, body mass index; IQR, interquartile range; NRS, numerical rating scale; RCR, rotator cuff repair; STD, standard deviation.

superior trunk group had 0 of 62 (0%) with partial paresis and 59 of 63 (95.2%) with no paresis.

The worst numerical rating scale pain scores in the recovery room were noninferior (0 [IQR 0, 2] *vs.* 0 [IQR 0, 3]; $P = 0.951$). The difference in the mean worst numerical rating scale pain scores in the recovery room between superior trunk block and interscalene block was −0.06, and the upper limit of the Hodges-Lehmann 97.5% CI was 0.0, which is less than the noninferiority margin (Delta = 1.6). Incidence of non-zero worst numerical rating scale pain score in the recovery room was 20 of 62 (32.3%) in the superior trunk group and 20 of 63 (31.8%) in the interscalene group ($P = 0.951$).

Numerical Rating Scale Pain Scores

Baseline numerical rating scale pain scores were not significantly different (2 [0, 3] *vs.* 2 [0, 3]; $P = 0.211$). Numerical rating scale pain scores at 60 min in the recovery room were noninferior (0 [0, 0] *vs.* 0 [0, 0]; $P = 0.668$). Incidence of non-zero pain scores 60 min after admissions to the recovery room was not significantly different between the superior trunk (10 of 62 [16.1%]) and interscalene (12 of 63 [19.1%]) groups ($P = 0.688$). The worst pain scores at rest on postoperative day 1 (4 [2, 5] *vs.* 4[3, 7]; $P = 0.049$) and with movement on postoperative day 2 (5 [4, 7] *vs.* 6 [5, 8]; $P = 0.043$) were significantly lower in the superior trunk group. At other time points, there was no difference between groups in worst pain scores at rest and with movement (table 2).

Respiratory Function, Diaphragmatic Excursion, and Oxygen Saturation

In the recovery room, the superior trunk group had greater preservation of mean minute ventilation and tidal volume than the interscalene group. In comparison with baseline measurements (table 3), mean minute ventilation has increased in the recovery room for the superior trunk group (7.2 ± 4.0 to 7.9 ± 4.8; $P = 0.143$), whereas it significantly decreased for the interscalene group (7.5 ± 4.8 to 6.7 ± 4.8; $P = 0.018$). Likewise, when comparing from baseline, the intraoperative mean minute ventilation measurements have significantly decreased for the interscalene group (7.5 ± 4.8 to 6.3 ± 4.9; $P = 0.003$) but not for the superior trunk group (7.2 ± 4.0 to 7.5 ± 4.5; $P = 0.49$).

Table 2. NRS Pain Scores and Opioid Consumption

	Superior Trunk Block (median [IQR])	Interscalene Block (median [IQR])	Mean Difference (95% CI)	*P* Value
NRS pain scores, 0–10				
Baseline NRS score	2 [0,3]	2[0,3]	0.6 (–0.1,1.3)	0.211
Worst NRS (PACU)	0 [0,2]	0 [0,3]	–0.04 (–0.7, 0.6)	0.951
NRS at 60 min (PACU)	0 [0,0]	0 [0,0]	–0.02 (–0.9, 0.9)	0.668
POD 1	4 [2,5]	4 [3,7]	–1.1 (–2.1, –0.1)	0.049
Worst NRS at rest				
Worst NRS during movement	5 [4,7]	6 [4,8]	–0.8 (–1.9, 0.4)	0.156
POD 2	4.5 [4,7]	5 [3,7]	–0.2 (–1.3, 0.8)	0.467
Worst NRS at rest				
Worst NRS during movement*	5 [4,7]	6 [5,8]	–1.0 (–2.0, 0.0)*	0.043
Opioid Consumption (OME), mg				
PACU	0 [0,7.5]	0 [0,7.5]	0.3 (–2.5, 3.0)	0.327
POD 1	15 [7.5,30]	22.5 [15, 30]	–2.8 (–9.4, 3.9)	0.159
POD 2	8.8 [7.5, 19.3]	9.4 [7.5, 15.0]	1.0 (–3.1, 5.0)	0.760

*Median difference (95% CI).

IQR, interquartile range; NRS, numerical rating scale; OME, oral morphine equivalents; PACU, postanesthesia care unit; POD, postoperative day.

Table 3. Respiratory Function: Impact of Nerve Block on Minute Ventilation

	Baseline, l/min (mean ± SD)	Intraoperative, l/min (mean ± SD)	Mean Difference (95% CI)	*P* Value	Recovery Room, l/min (mean ± SD)	Mean Difference (95% CI)	*P* Value
Superior trunk block	7.2 ± 4.0	7.5 ± 4.5	0.4 (–0.7,1.4)	0.49	7.9 ± 4.8	0.8 (–0.3, 1.8)	0.143
Interscalene block	7.5 ± 4.8	6.3 ± 4.9	–1.1 (–1.8, –0.4)	0.003	6.7 ± 4.8	–0.9 (–1.6, –0.2)	0.018

Table 4. Comparison between Nerve Blocks on Respiratory Function

	Superior Trunk Block*	Interscalene Block*	Mean Difference (95% CI)	*P* Value
Comparing baseline to recovery room				
Change in minute ventilation, l/min	0.8 ± 3.6	–0.9 ± 2.4	1.6 (0.4, 2.9)	0.001
Change in tidal volume, l	0.1 ± 0.2	–0.04 ± 0.2	0.01 (0.0, 0.2)	0.026
Change in respiratory rate, breaths/min	0.1 ± 2.6	–0.8 ± 3.2	0.9 (–0.3, 2.1)	0.080
Comparing baseline to intraoperative				
Change in minute ventilation, l/min	0.4 ± 3.5	–1.1 ± 2.6	1.5 (0.3, 2.7)	0.005
Change in tidal volume, l	0.01 ± 0.3	–0.1 ± 0.2	0.1 (–0.0, 0.2)	0.072
Change in respiratory rate, breaths/min	0.4 ± 3.23	–0.2 ± 3.0	0.6 (–0.6, 1.9)	0.256
Diaphragmatic excursion				
PACU diaphragmatic excursion, cm	4 [3, 4.5]	0 [0, 2]	2.9 (2.4, 3.4)	< 0.001
Diaphragmatic excursion reduction, cm	–1 [–1, –0.5]	–5 [–6, –3]	3.9 (3.3, 4.5)	< 0.001
Oxygen saturation				
PACU discharge oxygen saturation, %	97 [96, 99]	96 [95, 98]	0.7 (0.0, 1.4)	0.054
Oxygen saturation reduction, cm	0 [–2, 1]	–1 [–3, 0]	0.8 (0.1, 1.5)	0.040

*Changes in minute ventilation, tidal volume, and respiratory rates are presented as mean ± SD. Diaphragmatic excursion and oxygen saturation results are presented as median [IQR].

PACU, postanesthesia care unit.

When comparing between the two groups changes from baseline to recovery room (table 4), there were significant differences in the change of mean minute ventilation (0.8 ± 3.6 [superior trunk block] *vs.* −0.9 ± 2.4 [interscalene block]; $P = 0.001$) and mean tidal volume (0.1 ± 0.2 [superior trunk block] *vs.* −0.04 ± 0.2 [interscalene block]; $P = 0.026$). When comparing changes between baseline and intraoperative measurements, there were significant differences in mean minute ventilation (0.4 ± 3.5 [superior trunk block] *vs.* −1.1 ± 2.6 [interscalene block]; $P = 0.005$).

Diaphragmatic excursion reduction was significantly more in the interscalene group (−5 [−6, −3]) than the superior trunk group (−1 [−1, −0.5]; $P < 0.001$). There was no increased oxygen supplementation or use of bilevel positive airway pressure (used to assist patient's ventilation when complaining of severe dyspnea) between groups.

Table 5. Block Characteristics

	Superior Trunk Block (n = 62)*	Interscalene Block (n = 63)*	Risk or Mean Difference (95% CI)	*P* Value
Hemidiaphragmatic paralysis			−0.9 (−0.9, −0.8)†	< 0.001
Complete	3 (4.8%)	46 (73.0%)		
Partial	0 (0%)	11 (17.5%)		
No	59 (95.2%)	6 (9.5%)		
Adverse effects				
Hiccups	0	8 (12.7%)	−0.1 (−0.2, −0.0)†	0.006
Horner's syndrome or hoarseness	1(1.6%)	12 (19.1%)	−0.2 (−0.3, −0.1)†	0.001
Subjective dyspnea	0	3 (4.8%)	−0.1 (−0.01, .01)†	0.164
Handgrip strength (change from baseline)	−18.9 (−26.2, −11.8)	−20.0 (−27.1, −12.6)	−0.2 (−4.7, 4.4)	0.130
No motor strength (incidence of zero handgrip strength)	6 (10.5%)	11 (20.8%)	−0.1 (−0.2, 0.0)†	0.138
Block duration (median [IQR])	23.2 [19.1,30.1]	23.18 [20.0 25.5]	1.6 (−1.6, 4.8)	0.853
Conversion to general anesthesia	0	0	NA	NA
Neuropraxia	0	0	NA	NA
LAST	0	0	NA	NA
BiPAP	0	0	NA	NA
High oxygen requirements (≥ 5 l NC)	0 (0%)	2 (3.2%)	−0.03 (−0.1, 0.0)†	0.496
Other				
Patient satisfaction in PACU	9.7 ± 0.8	9.3 ± 0.9	0.3 (0.0, 0.7)†	0.031
Patient satisfaction in POD 1	9.4 ± 1.0	9.5 ± 1.0	−0.1 (−0.4, 0.3)†	0.774
Patient satisfaction in POD 2	9.1 ± 1.7	9.2 ± 1.3	−0.1 (−0.6, 0.5)†	0.789
Ready for PACU discharge, min	119.0 [96, 139]	134.9 [94, 161]	−16.0 (−33.9, 2.0)	0.173

*Handgrip strength and patient satisfaction are presented as mean ± SD. Block duration and ready for PACU discharge are presented as median [IQR].

†Risk difference (absolute difference in the proportion of patients experiencing the outcome, comparing superior trunk block with interscalene block; *e.g.*, risk of hemidiaphragmatic paralysis was 90% lower in the superior trunk block group compared with interscalene block).

BiPAP, bilevel positive airway pressure (used to assist patient's ventilation when complaining of severe dyspnea); IQR, interquartile range; LAST, local anesthetic systemic toxicity; NA, not applicable; NC, nasal cannula; PACU, postanesthesia care unit; POD, postoperative day.

However, there was more significant reduction in room air oxygen saturation among the interscalene group (−1 [−3, 0]) than the superior trunk group (−0 [−2, 1]; $P = 0.040$).

Opioid Consumption and Block Duration

To ensure that patients enrolled in the study were not opioid-tolerant, our exclusion criteria for eligibility included any patients with a history of chronic opioid use, defined as taking opioids for more than 3 months or daily oral morphine equivalents more than 5 mg/day for 1 month. There was no difference in opioid consumption in the recovery room, on postoperative day 1, or on postoperative day 2 (table 2). Further, there was no difference in block duration between groups (23.2 [19.1, 30.2] *vs.* 23.2 [20.0, 25.5]; $P = 0.853$).

Grip Strength, Adverse Effects, Time to Discharge, and Patient Satisfaction

There was no difference in average handgrip strength between the two groups (−18.9 [−26.2, −11.8] *vs.* −20.0 [−27.1, −12.6]; $P = 0.901$). The incidence of complete loss of motor strength was lower in the superior trunk group, but this did not reach statistical significance (6 of 57 [10.5%] *vs.* 11 of 53 [20.8%]; $P = 0.138$). There was a significantly higher incidence of Horner's syndrome or hoarseness (19.1% *vs.* 1.6%; $P = 0.001$) and hiccups (12.7% *vs.* 0%; $P = 0.006$) in the interscalene *versus* the superior trunk group. No patients complained of dyspnea in the superior trunk group, while three experienced such symptoms in the interscalene group. There was no occurrence of neuropraxia reported at the 1-week follow-up phone call. No difference in the time to discharge readiness was found (119.0 [96, 139] *vs.* 134.9 [94, 161]; $P = 0.173$). Patient satisfaction was marginally higher in the superior trunk *versus* interscalene group in the recovery room (9.7 ± 0.8 *vs.* 9.3 ± 0.9; $P = 0.031$), but no differences were detected on postoperative days 1 and 2 (table 5).

Discussion

In this randomized control trial, we compared the ultrasound-guided superior trunk block with the interscalene block for patients undergoing arthroscopic shoulder surgery. Our study demonstrated that the superior trunk block provides comparable anesthesia and analgesia with superior diaphragm sparing. Our study reports that the superior trunk block is a novel brachial plexus block technique that provides surgical anesthesia with significantly rare hemidiaphragmatic paralysis (4.8%).

Regional anesthesia for shoulder surgery has historically been performed by blocking the brachial plexus either at the level of the roots (interscalene) or at the level of the divisions (supraclavicular).[28] Despite efforts in lowering hemidiaphragmatic paralysis by modifying these surgical anesthetic

brachial plexus blocks, *e.g.*, low-volume interscalene and supraclavicular blocks, the incidences of hemidiaphragmatic paralysis remains high at 34 to 62.5%.[10,13] Recent literature highlights the strategies involved in reducing phrenic nerve paralysis, including limiting local anesthetic dose, volume, and injections remote from the C5–C6 nerve roots.[13,15,16] Even when performed under general anesthesia, with lower volumes to provide only postoperative analgesia (insufficient for surgical anesthesia), no studies targeting the brachial plexus have demonstrated an hemidiaphragmatic paralysis rate of less than 5%, with the best results reporting an incidence of 9 to 21%.[13,29] Although we report a significant improvement in preventing hemidiaphragmatic paralysis (4.8%), future studies should assess the minimum effective volume for the superior trunk block as a postoperative analgesic block. By shifting focus from surgical anesthesia to postoperative analgesia and performing general anesthesia with superior trunk block at even lower volumes (*e.g.*, 10 ml), the risk of hemidiaphragmatic paralysis may be eliminated altogether.

Because there are multiple nerves involved in the innervation of the shoulder joint (mostly suprascapular and axillary), combination peripheral nerve blocks have been investigated. Although many of these techniques have shown promise in sparing the phrenic nerve, none have been able to be reliable surgical anesthetic alternatives to the interscalene nerve block. Several studies recently published have shown mixed results.[30–33] The incidence of hemidiaphragmatic paralysis has not been assessed in these studies but is assumed to be nonexistent because of the distal location of the targeted nerves from the phrenic nerve. Only one study assessed respiratory function and found no significant difference between a combined suprascapular and axillary (circumflex) nerve block with interscalene block.[33] Despite the distal location of the blocks, patients still report 8.3% incidence of dyspnea.[32] Our study showed that minute ventilation and tidal volume did not decrease for the superior trunk block as it has for the interscalene block, and none of our patients reported dyspnea in the superior trunk group but 4.8% in the interscalene group. These blocks are technically more difficult, requiring more time, reportedly have higher failure rates,[31,32] and associated with higher opioid consumption.[31,32] In our study, we did not encounter the need to convert to general anesthesia for any patient in either group. Further, we found that the opioid-sparing effect of the interscalene block was preserved with the superior trunk group because there was no difference in pain scores or opioid consumption throughout the observation period. The reason for this finding can likely be explained by the fact that the superior trunk block represents a more proximal block approach to the brachial plexus with wide coverage. In comparison, peripheral nerve blocks performed individually have been shown to provide incomplete coverage.[31,32]

The novel anterior suprascapular approach[34,35] shows promise in providing noninferior analgesia to the interscalene block while preserving pulmonary function. As explained by Auyong *et al.*,[34] the mechanism of not needing to block the axillary nerve may be explained by the spread of local anesthetic to the posterior division of the superior trunk, thus partially blocking the brachial plexus. The authors showed that the diaphragmatic excursions did not change (1.7 ± 2.4; $P < 0.001$) with the suprascapular approach but did not report the incidence of hemidiaphragmatic paralysis. Interestingly, there were still 8% of patients in the suprascapular group that had subjective dyspnea (*vs.* 12% in the interscalene group). In our study, the superior trunk block was not associated with differential changes in minute ventilation or tidal volume in comparison with the interscalene block. The superior trunk group's minute ventilation and tidal volume increased in the recovery room, whereas the interscalene group's significantly decreased. Importantly, there were no patients in the superior trunk group reporting dyspnea, whereas there were 4.8% of patients in the interscalene group. By moving slightly more proximal and targeting the nerves as the suprascapular nerve exits the trunk, we are injecting the same volume but more effectively "blocking" the brachial plexus. This approach seems to allow for surgical anesthesia but is distal enough to spare the phrenic nerve. Given these findings, future studies should compare an anterior suprascapular nerve block to superior trunk block.

This study revealed the superior trunk block to be a superior alternative to the interscalene nerve block in preserving lung function (hemidiaphragmatic paralysis, minute ventilation, diaphragmatic excursion reduction, oxygen saturation) while providing noninferior surgical anesthesia and analgesia. When preservation of pulmonary function is important, the superior trunk block would be a viable and safer option to perform on a patient population (respiratory compromised) normally precluded from brachial plexus blockade.

The safety benefits accredited to the superior trunk block—lung preservation from phrenic sparing and handgrip strength preservation from partial brachial plexus blockade—can be attributed to the location (proximal to the exit of the suprascapular nerve from superior trunk) and volume (15 ml). As noted by Auyong *et al.*,[34] the posterior division of the superior trunk is in close proximity to the suprascapular nerve, not the anterior division, a correction of a longstanding misconception. It is this spatial relationship that may explain the analgesic potency of the superior trunk block and anterior suprascapular block. By directing a low volume to the proximal origin of the suprascapular nerve, it is likely to spread to the posterior divisions of the superior trunk. It is the posterior divisions that give rise to the axillary and subscapular nerves that also innervate the shoulder. A continuous catheter at the superior trunk may prolong the safer benefits of a single shot; however, future studies need to be done to determine the ideal rate of local

anesthetic to prevent spread to the phrenic nerve and inferior trunks.

Administering low volume (15 ml) has its own safety benefits. Postoperative neurologic symptoms have been shown to have a lower frequency of neurologic symptoms (0.3%) with local anesthetic volumes of 16 to 20 ml.[36] Low-volume interscalene block (20 ml) studies have demonstrated more sparing of handgrip,[8] likely as a consequence of limited spread to the inferior roots. Similarly, by limiting the spread to the superior trunk, there will be less motor blockade of the hand. Of the superior trunk group, 90% were able to move their hand, which may improve patient satisfaction. Studies have shown more patients becoming dissatisfied with prolonged motor blockade of the hand after shoulder surgery.[37] By isolating the superior trunk and limiting potential spread to the phrenic nerve, inferior trunks, and the recurrent laryngeal nerve, our study demonstrated the superior trunk group to benefit from less subjective dyspnea, hand immobility, and hoarseness. This may explain the superior trunk group's higher PACU patient satisfaction scores compared with the interscalene group.

Our study has a number of limitations. First, there were multiple anesthesiologists, including residents in training and fellows, who performed the blocks. This could lead to variability on accurate injection locations. However, we attempted to standardize the approach by agreeing to the technique to be used and closely supervising trainees to assure adherence to the latter. Second, there might be recall bias because postdischarge information were collected *via* phone call interview. Third, worst pain may not be the best measure to use to determine more important functional outcomes that better assess the quality of analgesia (*i.e.*, PainOUT questionnaire, Brief Pain Inventory Questionnaire).[38] Last, noninvasive respiratory monitoring may have limitations compared with the gold standard of spirometry.

In conclusion, this study shows that the superior trunk block can effectively provide surgical anesthesia and significantly reduce the rates of hemidiaphragmatic paralysis compared with the interscalene block. Future studies should be expanded to investigate its ability to safely provide surgical anesthesia to patients with severe pulmonary disease.

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Competing Interests

The authors declare no competing interests.

Reproducible Science

Full protocol available at: kimd@hss.edu. Raw data available at: kimd@hss.edu.

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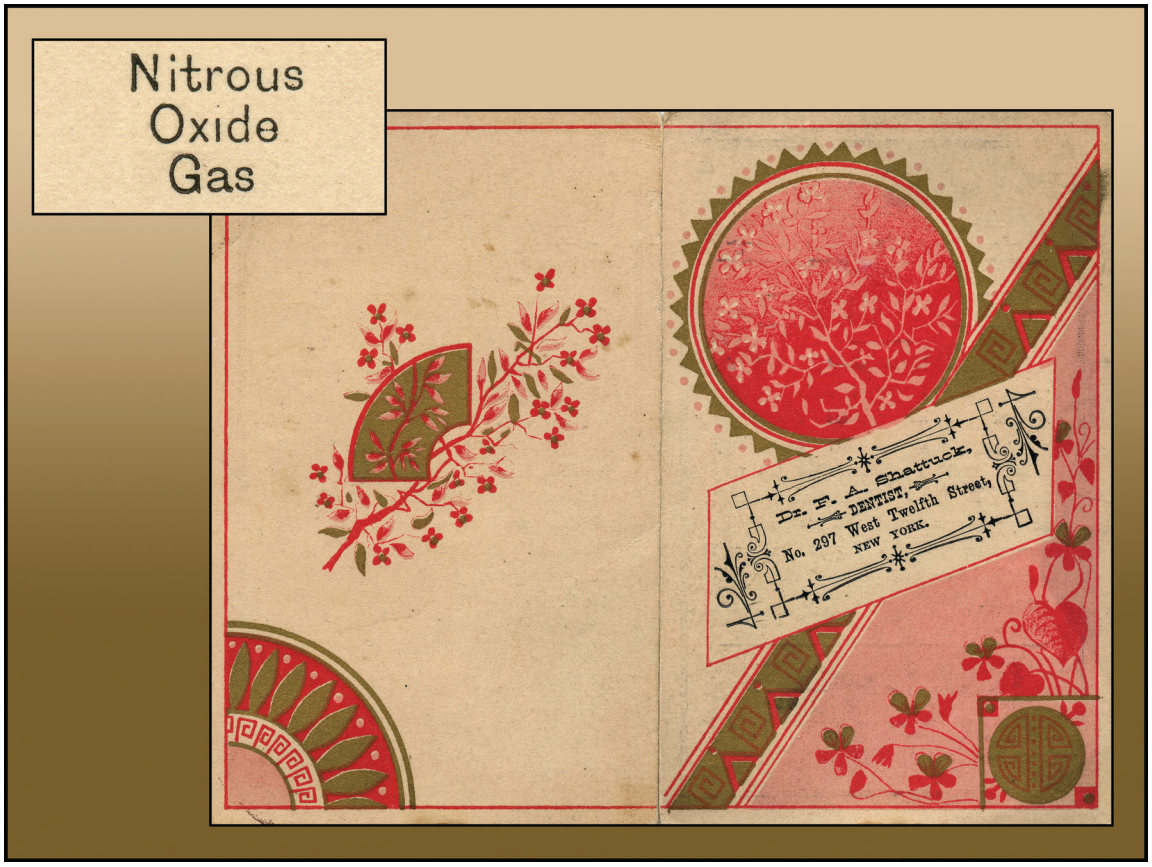
Dr. Frank A. Shattuck's Unfolding "Specialty, the Administration of Nitrous Oxide Gas"



According to New York City directories, Dr. Frank Alton Shattuck ran his dental office at 297 West Twelfth Street from roughly 1883 through 1887. So, this four-page advertising folder (*lower right*) was apparently printed sometime in the mid-1880s. Trained under a dental preceptor, Dr. Shattuck advertised his practice as embracing "all branches of the profession." On the inside of this elegant folder from the Wood Library-Museum's Ben Z. Swanson Collection, Dr. Shattuck trumpets that his practice includes "as a specialty, the administration of Nitrous Oxide Gas" (*upper left*). (Copyright © the American Society of Anesthesiologists' Wood Library-Museum of Anesthesiology.)

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