Pain Physician 2021; 24:507-515 • ISSN 1533-3159

Randomized Controlled Study

Hemidiaphragmatic Paresis Following Interscalene Brachial Plexus Block With 2-Point Injection Technique

Ki Seok Kim, MD, PhD[1], Jnug Hwan Ahn, MD[2], Ju Hyun Yoon, MD[3], Ho Tae Ji, MD[3], and Il Seok Kim, MD, PhD[3]

Background: An interscalene brachial plexus block is a commonly conducted nerve block for anesthesia and analgesia in shoulder surgery. Due to its proximity to the targeted nerve, the phrenic nerve, which innervates the diaphragm, is typically inadvertently blocked by ventral spread of the local anesthetic. Although hemidiaphragmatic paresis is tolerable in healthy patients, it would be an irreversible risk to patients with compromised lung reserve.

Objectives: To investigate the effect of interscalene brachial plexus block on hemidiaphragmatic paresis by comparing the conventional local anesthetic volume with a reduced experimental volume at a more specific position using an ultrasound-guided 2-point injection technique.

Study Design: Prospective, randomized controlled study registered with the Clinical Trial Registry of Korea (https://cris.nih.go.kr/cris/index.jsp. KCT0005575. 04/11/2020).

Setting: This study was conducted at a single hospital affiliated with an academic institution between April and December 2020.

Methods: Patients undergoing brisement manipulation and arthroscopic shoulder surgery were randomized to the experimental (10 mL of ropivacaine 0.5%) and control groups (15 mL of ropivacaine 0.5%). Fifty-two patients who received an interscalene brachial plexus block for anesthesia and analgesia in the shoulder region. The interscalene block was performed using a 2-point injection and observing the spread pattern of the local anesthetic. The primary outcome was the incidence of hemidiaphragmatic paresis, estimated by the thickening fraction of the diaphragm. The secondary outcomes included oxygen saturation, presence of dyspnea, resting pain score, and handgrip strength score.

Results: Thickening fraction was significantly decreased in the control group compared with the experimental group (median [interquartile range], 13.9 [10.0–18.5] versus 28.5 [14.5–38.8], $P < 0.001$). The incidence of hemidiaphragmatic paresis was significantly higher in the control group than in the experimental group (92.3% versus 53.8%, $P = 0.004$). Handgrip strength was significantly reduced in the control group compared with the experimental group ($P = 0.029$).

Limitations: We did not perform a phrenic nerve conduction study, as it is rarely performed in routine clinical operations. We did not formally assess the distance and spatial relationship of the phrenic nerve to the targeted nerve. Outcome variables including pain assessment were limited to the immediate postoperative period.

Conclusions: Reducing the local anesthetic volume by selective injection and observing the spread pattern resulted in a decreased incidence of hemidiaphragmatic paresis and preserved handgrip strength after interscalene block.

Key words: Arthroscopic shoulder surgery, brisement manipulation, diaphragm, hemidiaphragmatic paresis, interscalene brachial plexus block, local anesthetic, phrenic nerve, ultrasonography

Pain Physician 2021: 24:507-515

From: [1]Department of Medical Sciences, Hallym University Graduate School, Chuncheon, Republic of Korea; [2]Department of Emergency Medicine, Ajou University School of Medicine, Suwon, Republic of Korea; [3]Department of Anesthesiology and Pain Medicine, Kangdong Sacred Heart Hospital, Hallym University College of Medicine, Seoul, Republic of Korea

Address Correspondence:
Il Seok Kim, MD, PhD
Department of Anesthesiology and Pain Medicine, Kangdong Sacred Heart Hospital
Hallym University College of Medicine, 150 Sungan-ro, Gangdong-gu, Seoul 05355, Republic of Korea
E-mail: ilseokkim@naver.com

Disclaimer: Ki Seok Kim and Jung Hwan Ahn are first co-authors and contributed to the work equally. This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF), funded by the Ministry of Education, grant number 2018R1D1A1B07043429.

Manuscript received: 05-14-2021
Revised manuscript received: 07-29-2021
Accepted for publication: 08-31-2021

Free full manuscript:
www.painphysicianjournal.com

An interscalene brachial plexus block is a commonly conducted nerve block for anesthesia and analgesia in shoulder surgery (1). The principal targeting sites are the ventral rami of cervical nerve 5 (C5) and cervical nerve 6 (C6) or the superior trunk located in the posterior interscalene groove (2,3). Due to its proximity to the targeted nerve, the phrenic nerve is typically inadvertently blocked by ventral spread of the local anesthetic (4,5). Although hemidiaphragmatic paresis (HDP) is tolerable in healthy patients, it would be an irreversible risk to patients with compromised lung reserve.

Conventionally, a volume of 15 mL to 20 mL is administered to achieve adequate anesthesia and analgesia; the resulting incidence of HDP is high (up to 90%) (6-8). Several studies have been conducted to reduce the incidence of HDP based on the administered volume of the local anesthetic. A volume as small as 5 mL or 7 mL or an individualized volume of 1.7 mL for each trunk could reduce the incidence of HDP (9-12). However, an extremely low volume frequently predisposes the patient to incomplete coverage of anesthesia and inadequate potency of analgesia in a clinical setting. For instance, a dose of at least 10 mL of ropivacaine was needed to achieve sufficient analgesic efficacy with a duration of more than 10 hours (13). In addition to dose requirements, a single dose injection of local anesthetic around 2 nerve structures may prevent needle-to-nerve contact and/or needle repositioning. However, a single injection of 10 mL between the ventral rami of C5 and C6 does not reduce the incidence of HDP (14). By contrast, multipoint injection produces faster onset time and more accurate nerve targeting with a smaller anesthetic volume while sparing the adjacent nerves (12,15). Moreover, variability in location and splitting of the rami of C5 and C6 are commonly identified in the interscalene groove (2,16). With real-time visualization of the tissue plane of the needle tip and the spread pattern of the injection, it is possible to prevent an intraepineural administration of local anesthetic (17,18).

We hypothesized that administering a small dose of local anesthetic to the appropriate specific position selected by ultrasound would reduce complications of HDP while maintaining patient safety and analgesic efficacy. We investigated the effect of reduced local anesthetic volume on HDP after interscalene block using real-time ultrasound-guided 2-point injection with visualization of the spread pattern of the local anesthetic.

METHODS

Study Design and Ethics Statement

This prospective, randomized controlled study was conducted in patients who received an interscalene brachial plexus block for anesthesia and analgesia in the shoulder region. The study was conducted in accordance with the tenets of the Declaration of Helsinki and the study design was approved by a hospital institutional review board (approval number: 2020-02-020) between April and December 2020. All patients provided written informed consent before participation. This study was registered by the Clinical Trial Registry of the Republic of Korea (https://cris.nih.go.kr/cris/index.jsp. KCT0005575. 04/11/2020).

Study Population

We recruited 52 patients (age: 20–80 years) undergoing brisement manipulation for frozen shoulder and arthroscopic shoulder surgery for rotator cuff tear, biceps tendinosis, or Bankart lesion. Exclusion criteria included an existing severe respiratory disease, pregnancy, and a history of allergy to local anesthetics. Patients were randomly allocated to either the experimental or the control group using a computer-generated randomization. The experimental group received 10 mL of ropivacaine 0.5%, whereas the control group received 15 mL of ropivacaine 0.5%. Allocation information of the patients was concealed in sequentially numbered opaque envelopes, and the assignment envelope was opened by the anesthesiologist just before block performance.

Measurements

An investigator blinded to group assignment performed a diaphragmatic assessment on the side ipsilateral to the block using 2-dimensional mode ultrasonography (Affiniti70, Phillips, Andover, MA) with a high-frequency linear probe (L12-3 linear image transducer; Phillips). To assess diaphragm thickness in the intercostal region, the probe was positioned over the zone of apposition of the diaphragm between 2 ribs above the 8th or 9th intercostal space along the anterior axillary line by directing the ultrasound beam at right angles to the long axis of the intercostal space in the sagittal plane (19). The diaphragm was identified as a relatively hypoechoic central muscle layer encased by 2 distinct hyperechoic parallel lines of the parietal pleura and peritoneal fascia beneath the intercostal muscle. Encroachment of the diaphragm by sliding movement of lung tissue was observed with deep inspiratory effort. This transitional zone was the region of interest.

A dynamic image was obtained according to the respiratory cycle and stored as video clips. Diaphragm thickness at end expiration and peak inspiration during deep breathing was measured using still images from the video clip as the distance from the inner margin of the pleural membrane to the outer margin of the peritoneal membrane using internal electronic calipers (Fig. 1). The thickening fraction, defined as the percentage change in thickness between end expiration and peak inspiration, was calculated as follows: (thickness at peak inspiration – thickness at end expiration / thickness at end expiration) ×100. Three measurements were obtained and the median value was recorded.

After diaphragm assessment, an interscalene block was performed by hospital practitioners. Patients were positioned with the block-side shoulder elevated using a small pad and the head turned to the contralateral side. A prescan was performed using a dynamic traceback approach (20). After locating the neural cluster in the supraclavicular region, the probe was moved upward to identify the ventral rami of C5 and C6, shown as 2 or 3 hypoechoic round-shaped nerve components between the anterior and middle scalene muscles. Aberrant positions (i.e., ventral ramus of C5 positioned anterior to or passing through the anterior scalene muscle) and splitting of nerve components for the block site were recorded. The existence of adjacent blood vessels was inspected by color Doppler flow map.

After aseptic skin preparation and sterile draping, the block was performed with a 50 mm, 22-gauge insulated needle (UniPlex NanoLine, Pajunk Medical Produkte, Geisingen, Germany). The needle was inserted using an in-plane approach with a posterolateral-to-anteromedial direction superficial to the middle scalene muscle and advanced until the tip of the needle was positioned just posterior to the hyperechoic outer rim of the most upper C5 component without direct contact. After confirming the tip position with a one mL test volume of 0.5% ropivacaine, half of the predetermined volume in each group was injected slowly while observing the nerve components being pushed medially according to of the local anesthetic's spread (Fig. 2). If resistance to the injection was noted, or if the patient complained of paranesthesia, the injection was stopped immediately, and the needle tip was withdrawn and repositioned. In cases of circumferential spread of local anesthetic around the nerve component and craniocaudal distribution followed by separation of adjacent 2 nerve components, intraepineural and intrafascial administration were suspected and excluded from analysis. The needle tip was then redirected posterior to the outer hyperechoic rim of the lower C6 component and the remainder of the predetermined volume in each group was slowly injected.

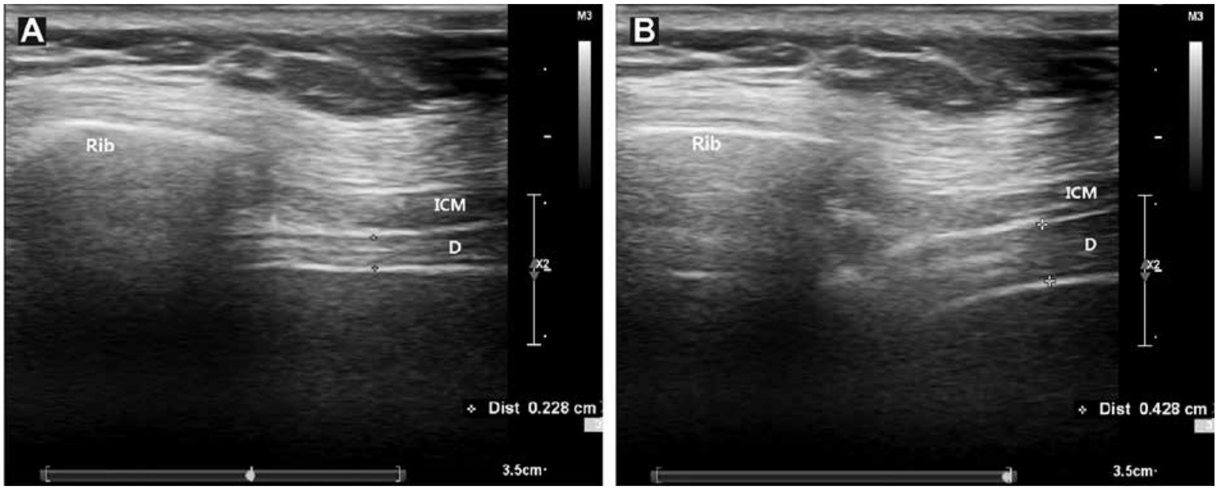

Fig. 1. *Ultrasound measurement of the diaphragm thickness according to active deep breathing. The diaphragm is identified as a relatively hypoechoic central muscle layer encased by 2 distinct hyperechoic parallel lines of the parietal pleura and peritoneal fascia. Diaphragm thickness at end expiration (A) and peak inspiration (B) is measured as the distance from the inner margin of the pleural membrane to the outer margin of the peritoneal membrane (between 2 crosses) using an internal electronic caliper. D, diaphragm; ICM, intercostal muscle.*

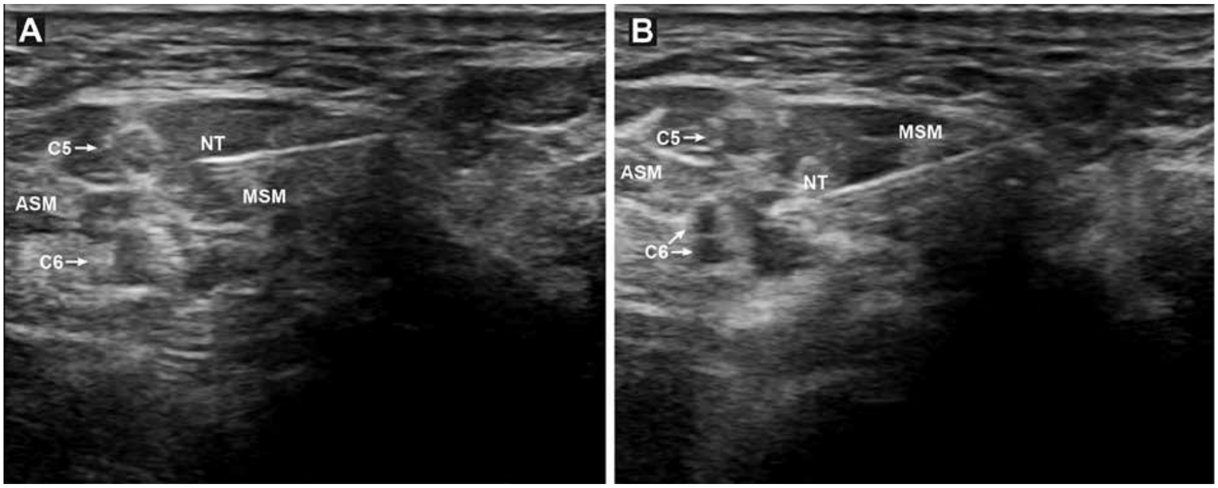

Fig. 2. *Ultrasound image of the interscalene block with a 2-point injection technique. The block needle is advanced until the needle tip is positioned posterior to the hyperechoic outer rim of the most upper cervical 5 nerve component (white arrow) while avoiding direct contact with the nerve component. First, half of the predetermined total volume is injected slowly while observing the nerve components being pushed medially according to the local anesthetic spread (A). The needle tip is then redirected posterior to the outer hyperechoic rim of the lower cervical 6 nerve components (white arrow) and the remainder of the predetermined total volume is slowly injected. A splitting of the ventral ramus of cervical nerve 6 is shown as 2 individual nerve components. Separation of adjacent 2 nerve components has not occurred (B). ASM, anterior scalene muscle; C5, cervical nerve 5; C6, cervical nerve 6; MSM, middle scalene muscle; NT, needle tip.*

No sedative drug was administered in patients undergoing brisement manipulation. Ten minutes after block performance, sensory block of the shoulder was assessed by a cold test in the deltoid area and graded on a 3-point scale (0 = not cold, one = less cold, and 2 = normal sensation). Motor block was assessed by asking the patient to perform a shoulder abduction and graded on a 3-point scale (0 = paralysis, 1 = paresis, and 2 = no block). Block success was defined as a sensory grade of 0 in the deltoid area. In cases of inadequate blockade, an additional 10 minutes was given for further distribution of the local anesthetic. A failed block was identified by performing a supplemental block or conversion to general anesthesia. After complete loss of sensation, brisement manipulation was performed by the surgeon and the patient was sent to the postanesthesia care unit (PACU).

According to the institutional standard, general anesthesia and tracheal intubation were performed in patients undergoing arthroscopic surgery. Anesthesia was maintained with 1.5% – 2.5% sevoflurane; no opioids were administered. At the end of the surgery, the surgeon inserted a port into the subacromial bursa to administer analgesia, but no additional local anesthetic was administered intraoperatively. After surgery, the patient was extubated with full recovery and transported to the PACU.

Thirty minutes after the patient's arrival in the PACU, the independent investigator blinded to group assignment assessed the diaphragm and evaluated sensory and motor block in the same manner as the preblock in each group.

Study Endpoint

The primary outcome was HDP incidence, estimated by the thickening fraction of the diaphragm. A lower thickening fraction in healthy volunteers during tidal breathing was determined to be 30%; therefore, HDP was defined as a thickening fraction less than 30% after block completion (21).

Secondary outcomes included oxygen saturation, presence of dyspnea, resting pain score, handgrip strength grade, and incidence of fingertip numbness. Oxygen saturation was measured by pulse oximetry at room air in the PACU. Dyspnea was defined as a pulse oximeter reading less than 90% or subjective symptom of chest discomfort during breathing. Resting pain was scored by an 11-point numerical rating scale (0 = no pain, 10 = the worst pain). A failed block was identified if the resting pain score exceeded 5 in the PACU.

Handgrip strength was assessed by asking the patient to hold a fist and squeeze the examiner's fingers and graded on a 3-point scale (0 = complete loss of power, 1 = weakness, 2 = normal). The presence of numbness in the distal fingers in the PACU was recorded.

Statistical Analysis

The sample size was calculated from data based on our preliminary study (unpublished) in which the patients were separated into 2 groups that were administered either 10 mL or 15 mL of ropivacaine 0.5%. Fifteen patients were included in each group and the incidence of HDP (thickening fraction of the diaphragm < 30%) was 47% (7/15) in the 10 mL group and 87% (13/15) in the 15 mL group. Based on the incidence rate, we calculated that 24 patients would be required in each group to detect a difference of this magnitude with an α error of 0.05 and a desired power of 0.80 using the Fisher's exact test in G*power statistical software version 3.1.9.2 (Franz Faul, University Kiel, Kiel, Germany). Allowing for a dropout rate of 10%, we recruited 52 patients to this study.

Statistical analysis was performed using the SPSS version 25.0 software (IBM Inc., Armonk, NY). Normal distribution of all outcome variables was assessed by the Shapiro-Wilk test. Continuous variables are expressed as the median (interquartile range) and were compared using an independent Student's t test or Mann-Whitney U test, whichever was deemed appropriate. Categorical variables are reported as the number (proportion) and were compared using the Pearson's χ^2 test or Fisher's exact test, whichever was deemed appropriate. Statistical significance was defined as $P < 0.05$.

RESULTS

Of the 52 patients enrolled in the study, 26 were allocated to the control group and 26 to the experimental group (Fig. 3). Demographic characteristics, clinical diagnosis, operation, the relative position of the ventral rami of C5 and C6 to the scalene muscles, aberrant positions and slitting of rami in ultrasound image were comparable between groups (Table 1).

There were no significant differences in thickening fraction before the block between the groups (Table 2). Thickening fraction after the block was significantly decreased in the control group (13.9 [10.0–18.5] versus

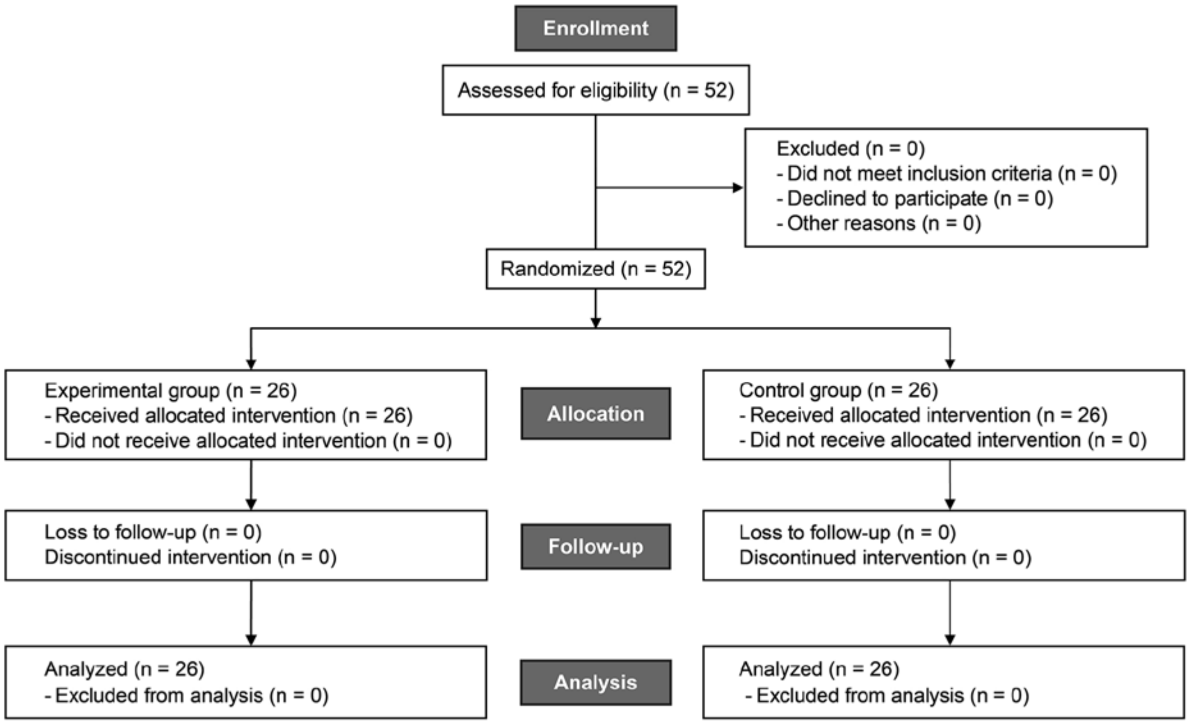

Fig. 3. *CONSORT flow diagram for patients included in the study.*

Table 1. Baseline characteristics of the study population.

Variable	**Experimental group (n = 26)**	**Control group (n = 26)**	***P* value**
Gender (men)	14 (53.8)	12 (46.2)	0.579
Age (years)	64.5 (56.0–71.3)	62.5 (56.0–68.3)	0.855
Height (cm)	161.7 (154.9–167.1)	160.5 (154.0–167.0)	0.621
Weight (kg)	64.3 (55.3–69.8)	69.4 (58.7–77.0)	0.051
Diagnosis			0.871
Adhesive capsulitis	14 (53.8)	13 (50.0)	
Rotator cuff tear	8 (30.8)	10 (38.5)	
Biceps tendon rupture	2 (7.7)	2 (7.7)	
Bankart lesion	2 (7.7)	1 (3.8)	
Operation			0.457
Brisement manipulation	13 (50.0)	13 (50.0)	
Arthroscopic surgery	10 (38.5)	12 (46.2)	
Mini open surgery	1 (3.8)	1 (3.8)	
Open surgery	2 (7.7)	0	
Relative position of the ventral rami of C5 and C6 to the scalene muscles			0.100
Between ASM and MSM	25 (96.2)	24 (92.3)	
C5 within ASM	1 (3.8)	2 (7.7)	
Splitting of the ventral rami of C5 and C6			0.382
No splitting	18 (69.2)	15 (57.7)	
C5, C6 splitting	1 (3.8)	0	
C6 splitting	7 (26.9)	11 (42.3)	

Values are reported as medians (interquartile range) or numbers (%). Abbreviations: ASM, anterior scalene muscle; C5, cervical nerve 5; C6, cervical nerve 6; MSM, middle scalene muscle.

Table 2. *Thickening fraction and hemidiaphragmatic paresis.*

Variable	**Experimental group (n = 26)**	**Control group (n = 26)**	***P* value**
TF			
Pre-block TF	48.5 (43.5–57.6)	45.5 (41.8–55.4)	0.431
Post-block TF	28.5 (14.5–38.8)	13.9 (10.0–18.5)	< 0.001*
Hemidiaphragmatic paresis			0.004*
Presence	14 (53.8)	24 (92.3)	
Absence	12 (46.2)	2 (7.7)	

Values are reported as medians (interquartile range) or numbers (%). *Statistically significant difference between groups. Abbreviation: TF, thickening fraction.

28.5 [14.5–38.8], $P < 0.001$). The incidence of HDP was significantly higher in the control group (92.3% [24/26] versus 53.8% [14/26], $P = 0.004$; Table 2).

During the injection of the nerve block, neither circumferential spread of local anesthetic around the nerve component nor craniocaudal separation of the adjacent 2 nerve components occurred in either group.

There were no differences between the groups in oxygen saturation, resting pain score, and incidence of fingertip numbness (Table 3). Dyspnea after the block occurred in 3 patients. Two patients in the control group complained of chest discomfort during deep breathing, while one patient in the experimental group developed dyspnea with desaturation of 89% following brisement manipulation and was managed with oxygen supplementation in the sitting position. All these patients had HDP with a reduced thickening fraction of 4.7% and 7.1% in the control group and 12.3% in the experimental group after interscalene block.

Handgrip strength was significantly reduced in the control group ($P = 0.029$). The incidence of complete weakness was lower in the experimental group (11.5% versus 34.6%) and the incidence of absence of weakness was higher in the experimental group (15.4% versus 0%). A failed block occurred in 2 patients. One patient in the control group reported a resting pain score of 6 after conversion of mini-open arthroplasty from the planned arthroscopic surgery. One patient in the experimental group complained of inadequate analgesia of the T1 nerve dermatome during brisement manipulation.

Neither adverse events, including hoarseness, Horner syndrome, and hiccups, nor complications, such as nerve injury, occurred in either group.

DISCUSSION

The principal finding of this study was that decreasing the volume of the local anesthetic from 15 mL to 10 mL in an interscalene brachial plexus block using an ultrasound-guided 2-point injection technique can reduce the incidence of HDP and preserve handgrip strength.

The phrenic nerve and the ventral ramus of C5 are separated by only 1.8 mm–2.0 mm at the cricoid cartilage level, and the distance between these 2 structures increases by an additional 3 mm for every centimeter of nerve length (4). HDP after interscalene block is dependent on the proximity of the targeting site to the phrenic nerve and volume of local anesthetic used.

A block placed at a more distal location, such as the supraclavicular region, could eliminate HDP by inhibiting direct spread of local anesthetic away from the phrenic nerve (6). However, this distal block could lead to insufficient analgesia for shoulder surgery by sparing the proximally located suprascapular nerve and the supraclavicular nerve arising from the superficial cervical plexus which supply the cutaneous cape area of the shoulder (22). In addition, there is concern about injury to the transverse cervical and dorsal scapular arteries (23). As an alternative to traditional interscalene block, a superior trunk block with selective targeting of the suprascapular nerve may be more difficult for an inexperienced practitioner (3). The spatial relationship between posterior and anterior divisions of the superior trunk and the suprascapular nerve, and the anatomical variation in the suprascapular nerve, such as premature taking-off to the superior trunk, should be considered to prevent incomplete block coverage (24).

A large volume of anesthetic (> 20 mL) can achieve analgesic efficacy but increases adverse effects (25). In comparison, volumes < 10 mL are proven to have efficacy and reduce the incidence of HDP, but there are concerns about incomplete anesthesia coverage, slow onset time, and precise neuro-localization required to achieve adequate analgesia in a clinical setting (9-12). In many institutions, 15 mL of local anesthetic is used for adequate anesthesia and analgesia of the shoulder region, with an incidence of HDP up to 90% (7,8). In a previous study (14), a single dose of 10 mL, injected between C5 and C6, reportedly resulted in a 93% incidence of HDP; this may be associated with the administration of local anesthetic within the fascial layer between C5 and C6, without observing spread patterns. We therefore hypothesized that reducing the volume to 10 mL and performing a selective injection to the targeted nerves, without intrafascial administration of local anesthetic, could achieve adequate potency and reduce the incidence of HDP compared to the conventional volume (15 mL). Therefore, 10 mL was determined to be the experimental volume.

Along the course of a nerve fascicle from the proximal to distal brachial plexus, the number of fascicles increases from mono-fascicular to a bi-fascicular or poly-fascicular nature and the relative ratio of nonneural to neural tissue component within the epineurium (surrounding the nerve fascicles) increases from 1:1 to 2:1 (26). On ultrasound, neural tissue is observed as a hypoechoic round structure and the layer of connective tissue is visualized as a hyperechoic envelope surrounding the neural tissue (27). Although it is difficult to distinguish between the fascial layer and the epineural layer with the current state of ultrasound technology, the spread pattern of local anesthetics could detect an intraepineural injection by neural swelling, and an intrafascial injection by craniocaudal distribution and separation of 2 adjacent nerve components (17,18).

Table 3. *Post-block outcome.*

Variable	Experimental group (n = 26)	Control group (n = 26)	*P* value
SpO_2	96.5 (95.0–97.0)	95.5 (94.0–97.0)	0.087
Dyspnea	1 (3.8)	2 (7.7)	0.101
Numerical rating scale	0 (0-0.25)	0 (0-0)	0.758
Handgrip strength			0.029*
Complete weakness	3 (11.5)	9 (34.6)	
Incomplete weakness	19 (73.1)	17 (65.4)	
Absence of weakness	4 (15.4)	0	
Numbness	10 (38.5)	10 (38.5)	1.000
Failed block	1 (3.8)	1 (3.8)	1.000

Values are reported as medians (interquartile range) or numbers (%). *Statistically significant difference between groups. Abbreviation: SpO_2, saturation of percutaneous oxygen.

A single injection of anesthetic far lateral to the junction between 2 hypoechoic nerve components has an advantage of less risk of inadvertent nerve injury (28). However, a single, small volume injection may lead to inadequate spread of the local anesthetic, being more or less an intramuscular injection within the middle scalene muscle, and would require more time for anesthetic effects. Moreover, if splitting of the ventral ramus of C6 is misinterpreted as 2 separate ventral rami of C6 and C7, injection between the nerve component could lead to intrafascial or intraepineural injection (29). A multipoint injection technique is often used to achieve faster onset time and adequate spread of local anesthetic around the plexus (12,15). As the location of C5 and splitting of C6 in the interscalene groove varies between individuals, more selective injections are needed (2,16). Real-time observation of the spread pattern of local anesthetic during the 2-point injection ensured that the needle tip was positioned just posterior to the hyperechoic outer connective tissue rim of individual nerve components without direct contact. Real-time observation also ensured the nerve components were pushed medially, and neither circumferential spread nor separation of the adjacent 2 components occurred. This method could provide a more selective block targeting the nerve using a small volume without intraepineural administration.

By administrating 2 small volume doses, we could achieve a satisfactory block quality with less HDP while preserving handgrip strength. Motor weakness of the hand is a concern in patients with outpatient surgery such as brisement manipulation. By limiting spread to other nerves, a decreased volume of local anesthetic reduced HDP and spared hand motor weakness.

In other studies, diaphragmatic excursion (that is, diaphragmatic movement according to respiration) identified diaphragmatic dysfunction (30,31). However, excursion does not provide specific anatomic information about the muscle itself and was influenced by the impedance of neighboring structures and abdominal compliance. A large range of diaphragmatic movement during deep inspiration would be difficult to detect using sonographic visualization of the diaphragmatic dome. Furthermore, a poor acoustic window due to the spleen would obscure visualization of the diaphragmatic dome in the left hemithorax (32).

Therefore, diaphragm thickness was used to assess muscle contractility quantitatively (33). The unit for measuring thickness is small (one mm), leading to interoperator variability and nonlinear differences in measurements according to patient weight and height, localization of the zone of apposition, and lung volume; therefore, isolated measurement is of little value for interpatient comparisons of diaphragm function. Variability in thickening fraction can be reduced by measuring the isolated thickness at end expiration and peak inspiration and then calculating a proportional change in thickness (21). This value provides a valid measurement of contractile capacity in intrapatient serial monitoring and interpatient comparisons (34). With a high resolution of superficial muscle contractility, thickening fraction can overcome the shortcomings of excursion about the acoustic window, and can be applied on both hemithoraces with high sensitivity and specificity for determining diaphragmatic dysfunction (35).

Limitations

There were several limitations to this study. First, we did not perform a phrenic nerve conduction study, considered the gold standard test, as it is uncomfortable to conscious patients and rarely performed in routine clinical operations. Second, we did not formally assess the distance and spatial relationship of the phrenic nerve to the targeted nerve. Practitioners blinded to the primary outcome did not specifically place the needle to look for the phrenic nerve and avoid it. Instead, practitioners only proceeded with the block, taking into account the variability in the course and location of the ventral rami of C5 and C6 within the interscalene groove. Further studies on needle placement to avoid phrenic nerve paralysis are needed. Third, outcome variables including pain assessment were limited to the PACU in the immediate postoperative period. Considering analgesic duration of 0.5% ropivacaine was approximately 10 hours–11 hours by volume of 10 mL–20 mL in another study, pain assessment during follow-up in the general ward would be complicated with multimodal, combined methods and the wear-off effect of local anesthetic (13). Fourth, we restricted the volume of local anesthetic to 10 mL and 15 mL in this study. The minimal effective volume for adequate analgesia, while sparing the phrenic nerve with a 2-point injection technique, is yet to be determined.

Conclusion

In conclusion, a low volume of local anesthetic in an interscalene brachial plexus block with a 2-point injection technique provided fewer incidences of HDP. Although HDP is not completely avoided with interscalene block, reducing the volume of local anesthetic while observing the spread pattern and injection to the selected nerve was able to preserve handgrip strength. Based on these findings, low volume and selective injection may be valuable in an interscalene block, especially in patients at high risk of respiratory complication and undergoing outpatient surgery who want to spare motor weakness of the hand.

References

1. Singelyn FJ, Lhotel L, Fabre B. Pain relief after arthroscopic shoulder surgery: A comparison of intraarticular analgesia, suprascapular nerve block, and interscalene brachial plexus block. *Anesth Analg* 2004; 99:589-592.
2. Franco CD, Williams JM. Ultrasound-guided interscalene block: Reevaluation of the "stoplight" sign and clinical implications. *Reg Anesth Pain Med* 2016; 41:452-459.
3. Burckett-St Laurent D, Chan V, Chin KJ. Refining the ultrasound-guided interscalene brachial plexus block: The superior trunk approach. *Can J Anaesth* 2014; 61:1098-1102.
4. Kessler J, Schafhalter-Zoppoth I, Gray AT. An ultrasound study of the phrenic

nerve in the posterior cervical triangle: Implications for the interscalene brachial plexus block. *Reg Anesth Pain Med* 2008; 33:545-550.

5. Stundner O, Meissnitzer M, Brummett CM, et al. Comparison of tissue distribution, phrenic nerve involvement, and epidural spread in standard- vs low-volume ultrasound-guided interscalene plexus block using contrast magnetic resonance imaging: A randomized, controlled trial. *Br J Anaesth* 2016; 116:405-412.
6. Kim BG, Han JU, Song JH, Yang C, Lee BW, Baek JS. A comparison of ultrasound-guided interscalene and supraclavicular blocks for post-operative analgesia after shoulder surgery. *Acta Anaesthesiol Scand* 2017; 61:427-435.
7. Kang R, Jeong JS, Chin KJ, et al. Superior trunk block provides noninferior analgesia compared with interscalene brachial plexus block in arthroscopic shoulder surgery. *Anesthesiology* 2019; 131:1316-1326.
8. Auyong DB, Hanson NA, Joseph RS, Schmidt BE, Slee AE, Yuan SC. Comparison of anterior suprascapular, supraclavicular, and interscalene nerve block approaches for major outpatient arthroscopic shoulder surgery: A randomized, double-blind, noninferiority trial. *Anesthesiology* 2018; 129:47-57.
9. Riazi S, Carmichael N, Awad I, Holtby RM, McCartney CJ. Effect of local anaesthetic volume (20 vs 5 ml) on the efficacy and respiratory consequences of ultrasound-guided interscalene brachial plexus block. *Br J Anaesth* 2008; 101:549-556.
10. Lee JH, Cho SH, Kim SH, et al. Ropivacaine for ultrasound-guided interscalene block: 5 mL provides similar analgesia but less phrenic nerve paralysis than 10 mL. *Can J Anaesth* 2011; 58:1001-1006.
11. Vandepitte C, Gautier P, Xu D, Salviz EA, Hadzic A. Effective volume of ropivacaine 0.75% through a catheter required for interscalene brachial plexus blockade. *Anesthesiology* 2013; 118:863-867.
12. Gautier P, Vandepitte C, Ramquet C, DeCoopman M, Xu D, Hadzic A. The minimum effective anesthetic volume of 0.75% ropivacaine in ultrasound-guided interscalene brachial plexus block. *Anesth Analg* 2011; 113:951-955.
13. Fredrickson MJ, Abeysekera A, White R. Randomized study of the effect of local anesthetic volume and concentration on the duration of peripheral nerve blockade. *Reg Anesth Pain Med* 2012; 37:495-501.
14. Sinha SK, Abrams JH, Barnett JT, et al. Decreasing the local anesthetic volume from 20 to 10 mL for ultrasound-guided interscalene block at the cricoid level does not reduce the incidence of hemidiaphragmatic paresis. *Reg Anesth Pain Med* 2011; 36:17-20.
15. Mittal K, Janweja S, Prateek, Sangwan P, Agarwal D, Tak H. The estimation of minimum effective volume of 0.5% ropivacaine in ultrasound-guided interscalene brachial plexus nerve block: A clinical trial. *J Anaesthesiol Clin Pharmacol* 2019; 35:41-46.
16. Sakamoto Y. Spatial relationships between the morphologies and innervations of the scalene and anterior vertebral muscles. *Ann Anat* 2012; 194:381-388.
17. Spence BC, Beach ML, Gallagher JD, Sites BD. Ultrasound-guided interscalene blocks: Understanding where to inject the local anaesthetic. *Anaesthesia* 2011; 66:509-514.
18. Maga J, Missair A, Visan A, et al. Comparison of outside versus inside brachial plexus sheath injection for ultrasound-guided interscalene nerve blocks. *J Ultrasound Med* 2016; 35:279-285.
19. Tsui JJ, Tsui BC. A novel systematic ABC approach to diaphragmatic evaluation (ABCDE). *Can J Anaesth* 2016; 63:636-637.
20. Tsui BC, Lou L. Learning the 'traceback' approach for interscalene block. *Anaesthesia* 2014; 69:83-85.
21. Goligher EC, Laghi F, Detsky ME, et al. Measuring diaphragm thickness with ultrasound in mechanically ventilated patients: Feasibility, reproducibility and validity. *Intensive Care Med* 2015; 41:642-649.
22. Maybin J, Townsley P, Bedforth N, Allan A. Ultrasound guided supraclavicular nerve blockade: First technical description and the relevance for shoulder surgery under regional anaesthesia. *Anaesthesia* 2011; 66:1053-1055.
23. Murata H, Sakai A, Hadzic A, Sumikawa K. The presence of transverse cervical and dorsal scapular arteries at three ultrasound probe positions commonly used in supraclavicular brachial plexus blockade. *Anesth Analg* 2012; 115:470-473.
24. Harry WG, Bennett JD, Guha SC. Scalene muscles and the brachial plexus: Anatomical variations and their clinical significance. *Clin Anat* 1997; 10:250-252.
25. Maalouf DB, Dorman SM, Sebeo J, et al. Prospective, randomized double-blind study: Does decreasing interscalene nerve block volume for surgical anesthesia in ambulatory shoulder surgery offer same-day patient recovery advantages? *Reg Anesth Pain Med* 2016; 41:438-444.
26. Moayeri N, Bigeleisen PE, Groen GJ. Quantitative architecture of the brachial plexus and surrounding compartments, and their possible significance for plexus blocks. *Anesthesiology* 2008; 108:299-304.
27. van Geffen GJ, Moayeri N, Bruhn J, Scheffer GJ, Chan VW, Groen GJ. Correlation between ultrasound imaging, cross-sectional anatomy, and histology of the brachial plexus: A review. *Reg Anesth Pain Med* 2009; 34:490-497.
28. Palhais N, Brull R, Kern C, et al. Extrafascial injection for interscalene brachial plexus block reduces respiratory complications compared with a conventional intrafascial injection: A randomized, controlled, double-blind trial. *Br J Anaesth* 2016; 116:531-537.
29. Orebaugh SL, McFadden K, Skorupan H, Bigeleisen PE. Subepineurial injection in ultrasound-guided interscalene needle tip placement. *Reg Anesth Pain Med* 2010; 35:450-454.
30. Boussuges A, Gole Y, Blanc P. Diaphragmatic motion studied by m-mode ultrasonography: Methods, reproducibility, and normal values. *Chest* 2009; 135:391-400.
31. Lerolle N, Guérot E, Dimassi S, et al. Ultrasonographic diagnostic criterion for severe diaphragmatic dysfunction after cardiac surgery. *Chest* 2009; 135:401-407.
32. Haji K, Royse A, Tharmaraj D, Haji D, Botha J, Royse C. Diaphragmatic regional displacement assessed by ultrasound and correlated to subphrenic organ movement in the critically ill patients--An observational study. *J Crit Care* 2015; 30:439.e7-439.e13.
33. Boon AJ, Harper CJ, Ghahfarokhi LS, Strommen JA, Watson JC, Sorenson EJ. Two-dimensional ultrasound imaging of the diaphragm: Quantitative values in normal subjects. *Muscle Nerve* 2013; 47:884-889.
34. Ferrari G, De Filippi G, Elia F, Panero F, Volpicelli G, Aprà F. Diaphragm ultrasound as a new index of discontinuation from mechanical ventilation. *Crit Ultrasound J* 2014; 6:8.
35. Boon AJ, Sekiguchi H, Harper CJ, et al. Sensitivity and specificity of diagnostic ultrasound in the diagnosis of phrenic neuropathy. *Neurology* 2014; 83:1264-1270.