ORIGINAL ARTICLE

Reduced Hemidiaphragmatic Paresis With a "Corner Pocket" Technique for Supraclavicular Brachial Plexus Block

Single-Center, Observer-Blinded, Randomized Controlled Trial

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Background and Objective: Hemidiaphragmatic paresis is common after supraclavicular brachial plexus block (SCBPB). In this randomized trial, we compared the incidence of hemidiaphragmatic paresis in patients who had local anesthetic injected primarily in the corner pocket (defined as the intersection of the first rib and subclavian artery) during SCBPB with that of patients who underwent injection primarily inside the neural cluster.

Methods: Thirty-six patients scheduled for right elbow, forearm, wrist, or hand surgery under SCBPB (using 12.5 mL of 0.75% ropivacaine and 12.5 mL of 2% lidocaine with 1:200,000 epinephrine) were randomly assigned to 1 of 2 groups. In group CP, local anesthetic was injected primarily in the corner pocket (20 mL) and secondarily inside the neural cluster (5 mL). In group NC, local anesthetic was deposited primarily inside the neural cluster (20 mL) and secondarily in the corner pocket (5 mL). The primary outcome was the incidence of hemidiaphragmatic paresis, as measured by M-mode ultrasonography 30 minutes after SCBPB.

Results: The incidence of hemidiaphragmatic paresis was significantly lower in group CP than in group NC (27.8% vs 66.7%, $P = 0.019$). The median decreases in forced expiratory volume at 1 second (7.5% [interquartile range, 3.3%–17.1%] vs 24.4% [interquartile range, 10.2%–31.2%]; $P = 0.010$) and forced vital capacity (6.4% [interquartile range, 3.3%–11.1%] vs 19.3% [interquartile range, 13.7%–33.2%]; $P = 0.001$) were also lower in group CP than in group NC.

Conclusions: The incidence of hemidiaphragmatic paresis was effectively reduced when local anesthetic was injected primarily in the corner pocket during right-sided SCBPB. However, the 28% incidence of hemidiaphragmatic paresis associated with the corner pocket technique may still represent a prohibitive risk for patients with preexisting pulmonary compromise.

Clinical Trial Registration: This study was registered at Clinical Trial Registry of Korea, identifier KCT0001769.

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Supraclavicular brachial plexus block (SCBPB) is widely used to provide anesthesia for upper extremity surgery. The incidence of hemidiaphragmatic paresis following SCBPB can reach 50%, depending on the volume of local anesthetic and the use of ultrasonography.[1–3] Possible mechanisms include direct spread of local anesthetic to the phrenic nerve or retrograde diffusion to the C3 to C5 nerve roots.[3] Although transient hemidiaphragmatic paresis is well tolerated in healthy individuals,[4] patients with preexisting pulmonary disease may suffer from respiratory complications.[5] Ultrasound guidance has been advocated to curtail the incidence of hemidiaphragmatic paresis after SCBPB.[3] Among the various techniques described for ultrasound-guided SCBPB,[6] the "corner pocket" method whereby local anesthetic is injected at the intersection of the first rib and subclavian artery seems to confer high efficacy and a comparable success rate to direct local anesthetic injection inside the neural cluster.[7–9] Because the corner pocket is anatomically separated from the phrenic nerve by the anterior scalene muscle, the risk of hemidiaphragmatic paresis could be theoretically reduced with this technique. Thus, in a randomized trial, we set out to compare the incidence of hemidiaphragmatic paresis in patients who had a local anesthetic injection primarily in the corner pocket during SCBPB to that of patients who underwent injection primarily inside the neural cluster.

METHODS

Study Participants

After approval by the Samsung Medical Center Institutional Review Board (identifier SMC 2015-03-084), this trial was prospectively registered at the Clinical Trial Registry of Korea (http://cris.nih.go.kr; identifier KCT0001769). We prepared this study article in accordance with the Consolidated Standards of Reporting Trials guidelines.[10] Written informed consent was obtained from all participants. Forty adult patients scheduled for right elbow, forearm, wrist, or hand surgery under SCBPB were enrolled between January 2016 and May 2017. Patients with hepatic disease, renal disease, an American Society of Anesthesiologists (ASA) Physical Status higher than III, or moderate to severe decrease in preoperative pulmonary function were excluded.[11]

Randomization and Blinding

Using a computer-generated randomization tool (www.randomizer.org), patients were randomly assigned to a corner pocket (CP) or a neural cluster (NC) group. Group assignment was conducted using sequentially numbered, sealed opaque envelops. After patient enrollment, the latter were opened by a single anesthesiologist (D.H.C.) who performed all the blocks and who was not involved in subsequent data acquisition or outcome analysis. Outcomes (ie, ultrasound-guided diaphragm motion check, spirometry test, and sensorimotor block evaluation) were assessed by 1 of 2 anesthesiologists (R.A.K. and Y.H.C.) who were blinded to group assignments. Patients and the single surgeon who performed all the operations were also blinded to group allocation.

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Supraclavicular Brachial Plexus Block Technique

Supraclavicular brachial plexus block was performed in a dedicated block room before surgery. Standard patient monitoring included electrocardiogram, noninvasive blood pressure measurement, and pulse oximetry. Intravenous midazolam (1–2 mg) was administered for anxiolysis. Patients were positioned supine with the head slightly elevated and turned toward the contralateral side. After sterile skin preparation with 2% chlorhexidine/70% isopropyl alcohol and subcutaneous infiltration with 1 mL of 1% lidocaine, under ultrasound guidance (X-Porte; FUJIFILM SonoSite, Bothell, Washington), a sterile 22-gauge, 50-mm insulated nerve stimulating needle (PAJUNK, Geisingen, Germany) was inserted using an in-plane technique and a lateral-to-medial direction. The first target was the corner pocket (ie, intersection of the first rib and the subclavian artery). Subsequently, the needle was repositioned under direct vision and directed toward the neural cluster formed by the trunks and divisions of the brachial plexus. This second target is usually located superolateral to the subclavian artery (Fig. 1).[6] After negative aspiration, each group was administered a combined total of 25 mL of an identical local anesthetic mix (12.5 mL of 2% lidocaine and 12.5 mL of 0.75% ropivacaine with epinephrine 5 μg/mL). In group CP, 20 mL of local anesthetic was initially injected in the corner pocket, and the remaining 5 mL was deposited inside the neural cluster. In group NC, 5 and 20 mL were injected in the corner pocket and in the neural cluster, respectively.

Block Assessment

After SCBPB, sensory and motor blocks were assessed every 10 minutes over the course of 30 minutes. Sensory block was evaluated with pinprick testing in the distributions of the musculocutaneous, radial, median, and ulnar nerves and was graded on a 3-point scale (0 = normal sensation, 1 = loss of sensation to pinprick, and 2 = loss of sensation to light touch).[6,12] Motor block was evaluated using elbow flexion (musculocutaneous nerve), thumb abduction (radial nerve), thumb opposition (median nerve), and thumb adduction (ulnar nerve) and was also graded on a 3-point scale (0 = no block, 1 = paresis, and 2 = paralysis). Block success was defined as a minimal sensorimotor composite score of 14 points (out of 16 points) within 30 minutes of local anesthetic injection.

Assessment of Diaphragmatic Movement and Pulmonary Function

The primary outcome was the incidence of hemidiaphragmatic paresis 30 minutes after the injection of local anesthetic. Diaphragmatic movement was evaluated in the right subcostal margin with patients placed in the sitting position. M-mode ultrasonography[13,14] and a 5–2-MHz curvilinear transducer (Edge; FUJIFILM SonoSite) were used. The liver served as an acoustic window.[14] Diaphragmatic excursion was measured in centimeters during quiet breathing and deep breathing. The decrease in diaphragmatic excursion was calculated as the difference (in percentage) in diaphragmatic excursion measured before and 30 minutes after SCBPB. Each test was performed 3 times, and the values were averaged. Complete, partial, and no hemidiaphragmatic pareses were individually defined as decreases between 75% and 100% (or the occurrence of paradoxical movement), decreases between 25% and 75%, and decreases of less than 25% in diaphragmatic motion, respectively. Overall, we considered hemidiaphragmatic paresis to be present if partial or complete paresis occurred.[2,3,12,14,15] Pulmonary function was evaluated using a bedside spirometer (Micro Spirometer; Micro Medical Limited, Rochester, United Kingdom)[16] with patients placed in the sitting position. Forced expiratory volume at 1 second (FEV_1) and forced vital capacity (FVC) were measured 3 times, and the values were averaged. All

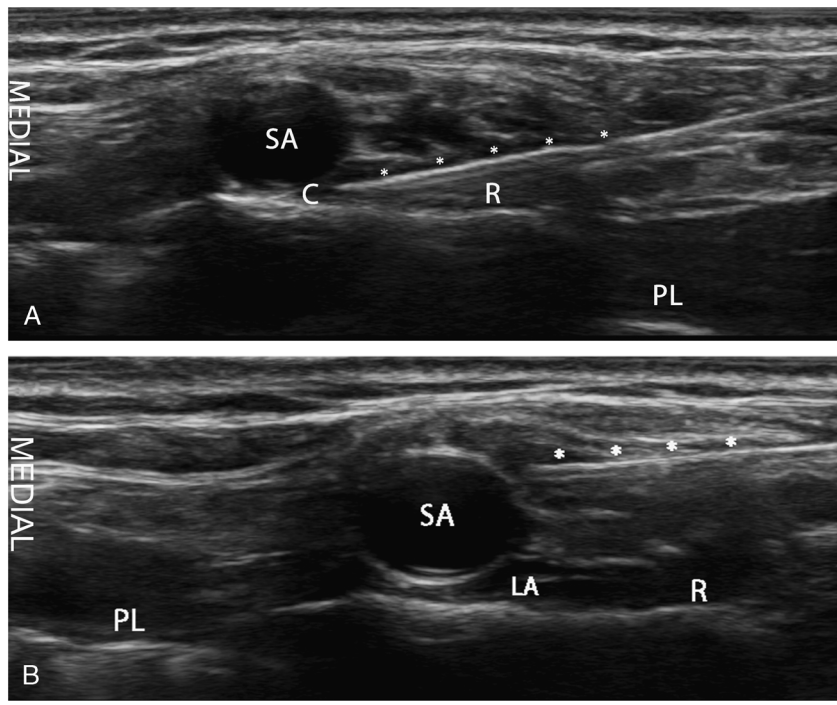

FIGURE 1. Transverse sonogram in the supraclavicular region. A, The needle (asterisk) was initially inserted into the corner pocket, and then (B) the needle was repositioned toward the nerve cluster. C indicates corner pocket; L, local anesthetic; PL, pleura; R, first rib; S, subclavian artery.

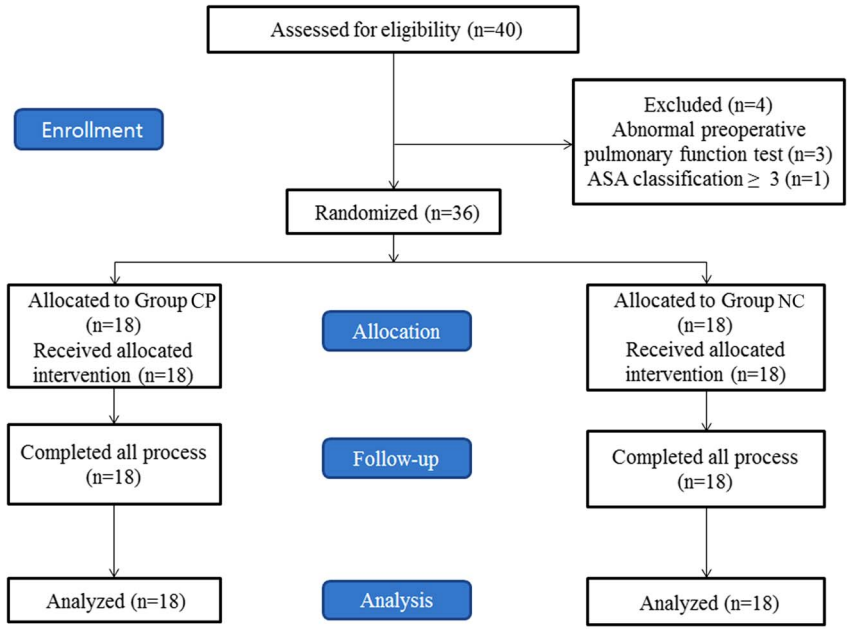

FIGURE 2. Overall flow diagram of the study according to Consolidated Standards of Reporting Trials guidelines.

measurements were carried out before (baseline) and 30 minutes after SCBPB. Patients were closely monitored in the perioperative period for symptoms and signs of respiratory distress.

Intraoperative and Postoperative Assessment

Following the final assessments (30 minutes), patients were transferred to the operating room for surgery with SCBPB as the primary anesthetic. The latter also included light conscious sedation. An attending anesthesiologist recorded instances requiring unscheduled conversion to general anesthesia or supplemental local anesthetic infiltration by the surgeon. Postoperative pain was measured in the postanesthesia care unit (PACU) with a numeric rating scale (NRS; 0 = no pain, 10 = worst imaginable pain). The total dose of analgesic administered in the PACU was also tabulated.

Sample Size and Statistical Analysis

In a preliminary (unpublished) study, the incidence of hemidiaphragmatic paresis was 66.7% in patients who underwent SCBPB with local anesthetic injection primarily inside the neural cluster (n = 9). In contrast, patients who received local anesthetic injection in the corner pocket (n = 9) displayed a 22.2% rate of hemidiaphragmatic paresis. We calculated that 18 patients per group would be required in order to detect this degree of difference with an $\alpha = 0.05$ and a power of 80%. Assuming a 10% dropout rate, we planned to recruit a total of 40 patients (20 subjects for each group). Data analysis was conducted according to an intent-to-treat analysis using SPSS software (SPSS 20.0; SPSS Inc, Chicago, Illinois). A *t* test or Mann-Whitney *U* test was used for continuous variables. A χ^2 test or Fisher exact test was used for categorical variables. $P < 0.05$ was considered significant.

RESULTS

A total of 40 patients were enrolled. Three subjects with moderate to severe decrease in pulmonary function and 1 patient with an ASA physical status higher than III were excluded. The remaining 36 patients were randomly assigned to 1 of the 2 groups (Fig. 2). There were no intergroup differences in terms of demographic data (Table 1). All patients underwent successful SCBPB. During surgery, no patients required conversion to general anesthesia or supplemental local infiltration by the surgeon.

The incidence of hemidiaphragmatic paresis was significantly lower in group CP than in group NC (27.8% vs 66.7%, $P = 0.019$) (Table 2). The median reduction in diaphragmatic excursion on deep breathing was also lower in group CP than compared with group NC (10.8% [interquartile range, 5.7%–36.3%] vs 39.6% [interquartile range, 19.8%–69.4%]; $P = 0.005$). Moreover, the median decreases in FEV_1 (7.5% [interquartile range, 3.3%–17.1%] vs 24.4% [interquartile range, 10.2%–31.2%]; $P = 0.010$) and FVC (6.4% [interquartile range, 3.3%–11.1%] vs 19.3% [interquartile range, 13.7%–33.2%]; $P = 0.001$) also favored group CP over group NC.

One patient in group NC complained of mild dyspnea 10 minutes after SCBPB. Symptoms subsided with the

TABLE 1. Baseline Characteristics and Clinical Data

	Group CP (n = 18)	Group NC (n = 18)
Age, y	44 ± 15	38 ± 17
Sex (male/female), n	12/6	12/6
Body mass index, kg/m^2	24.5 ± 2.9	24.1 ± 2.5
ASA class (I/II), n	14/4	16/2
Surgery time, min	83 (24–162)	65 (27–148)
Surgical procedure, n		
Forearm/elbow	5	6
Wrist	9	6
Hand	4	6

Data are presented as mean ± SD, median (interquartile range), or number.

TABLE 2. Comparison of the Incidence of Hemidiaphragmatic Paresis and Pulmonary Function–Related Parameters

	Group CP (n = 18)	Group NC (n = 18)	*P*
Hemidiaphragmatic paresis, n	5	12	0.019*
No paresis/partial paresis/complete paresis, n	13/4/1	5/9/4	
Diaphragmatic movements			
Diaphragmatic excursion on deep breathing at baseline, cm	4.1 ± 1.9	5.0 ± 1.8	0.143
Diaphragmatic excursion on deep breathing at 30 min after SCBPB, cm	3.2 ± 1.7	2.9 ± 1.7	0.574
Decreases in diaphragmatic excursion on deep breathing, %	10.8 (5.7–36.3)	39.6 (19.8–69.4)	0.005*
Pulmonary function test			
FEV_1 at baseline, L	2.6 ± 0.6	2.8 ± 0.8	0.400
FEV_1 at 30 min after SCBPB, L	2.4 ± 0.7	2.2 ± 0.9	0.376
Decreases in FEV_1, %	7.5 (3.3–17.1)	24.4 (10.2–31.2)	0.010*
FVC at baseline, L	3.0 ± 0.7	3.2 ± 0.8	0.444
FVC at 30 min after SCBPB, L	2.8 ± 0.7	2.5 ± 0.8	0.228
Decreases in FVC, %	6.4 (3.3–11.1)	19.3 (13.7–33.2)	0.001*

Data are presented as mean ± SD, median (interquartile range), or number.

*$P < 0.05$ between the 2 groups.

administration of oxygen and the sitting position. No other SCBPB-related complication was noted in either group. After surgery, no patient reported subjective dyspnea. Postoperative NRS pain scores in the PACU were similar in both groups (0.2 ± 0.7 vs 0.1 ± 0.7, $P > 0.999$). One patient (group CP) received intravenous ketorolac (30 mg) because of mild pain at the surgical site (NRS score = 3).

DISCUSSION

In this randomized trial, we demonstrated that, with SCBPB, the incidence of hemidiaphragmatic paresis can be effectively reduced when the local anesthetic is primarily injected in the corner pocket compared with the neural cluster. Furthermore, FEV_1 and FVC also seem to be better preserved with the corner pocket technique.

In most patients, the phrenic nerve originates from the C4 nerve root with contributions from C3 and C5 nerve roots. It travels obliquely on the ventral surface of the anterior scalene muscle, posterior to the prevertebral fascia, and descends through the neck deep to the inferior belly of the omohyoid muscle.[17] Subsequently, the phrenic nerve enters the thorax and runs anterior to the subclavian artery and posterior to the subclavian vein.[17,18] One possible explanation for hemidiaphragmatic paresis after SCBPB is retrograde diffusion of local anesthetic from the injection site (trunks/divisions of the brachial plexus) to the level of the cervical nerve roots. This may occur if a large amount of local anesthetic is injected into the relatively confined space. Alternately, local anesthetic could simply spread from the injection site to the phrenic nerve itself (ventral surface of the anterior scalene muscle). Our working hypothesis was that the corner pocket technique would counteract the second possible etiology. Although the physical distance between the corner pocket and the phrenic nerve is inferior to the one separating the neural cluster and the phrenic nerve, we speculated that the anterior scalene muscle would act as a physical barrier,[19] thereby promoting cephalocaudal spread of local anesthetic but preventing diffusion to its ventral surface. Although our results seem to support this hypothesis, further studies are warranted to elucidate SCBPB-induced hemidiaphragmatic paresis.

Previously, several strategies have been proposed to circumvent the risk of hemidiaphragmatic paresis with SCBPB. Arguably, the most successful one was the use of ultrasound guidance. In 2009, Renes et al[3] reported that, compared with neurostimulation, ultrasonography eliminated the risk of hemidiaphragmatic paresis during SCBPB. However, in our study, ultrasound guidance did not sidestep hemidiaphragmatic paresis even in the CP group. We speculate that these discordant findings could be explained by differences in local anesthetic volume and injection sites.[12,20] For ultrasound-guided SCBPB, the minimal effective volume in 90% of patients was 32 mL for 1.5% lidocaine[21] or 30 mL for 1% mepivacaine,[22] respectively. On the other hand, Renes et al[3] used 20 mL of 0.75% ropivacaine with good success and without hemidiaphragmatic paresis. Based on these findings, we selected 25 mL as a middle ground (between 20 and 30 mL) in order to maximize efficacy and minimize hemidiaphragmatic paresis. Perhaps the additional 5 mL and, more importantly, their injection in the neural cluster could explain the 28% incidence of hemidiaphragmatic paresis in our CP group.

Our study contains several limitations. First, most trials[2,3,12,15] (including ours) have defined hemidiaphragmatic paresis in absolute terms (ie, complete vs no paresis). However, complete or absent hemidiaphragmatic paresis cannot be ascertained by ultrasound only.[23] Confirmation of diaphragmatic dysfunction requires transdiaphragmatic pressure measurement combined with electromyographic recordings during phrenic nerve stimulation.[24] We decided to forego such evaluations because of the technical difficulty, invasiveness, and high false-positive rate associated with electrodiagnostic studies.[23] Second, although the corner pocket technique reduced the occurrence of hemidiaphragmatic paresis, the 28% incidence still constitutes a prohibitive risk in patients with preexisting pulmonary compromise. Third, our results should not be extrapolated to other local anesthetic agents or volumes and concentrations. Finally, we enrolled only patients who underwent orthopedic surgery on the right side because hemidiaphragmatic movement on the left side can be difficult to visualize with a splenic window.[13] Thus, further investigation is warranted for left-sided SCBPB.

In conclusion, the incidence of hemidiaphragmatic paresis can be effectively reduced when local anesthetic is deposited primarily in the corner pocket compared with primary injection inside the neural cluster. However, the 28% incidence of hemidiaphragmatic paresis associated with the corner pocket technique may still represent a prohibitive risk for patients with preexisting pulmonary compromise.

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