Local and Regional Anesthesia

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ORIGINAL RESEARCH

Retrospective Comparison of Extrafascial versus Intrafascial Interscalene Brachial Plexus Block with Reduced Volume: Impact on Hemidiaphragmatic Paralysis and Hemodynamic Effects in Shoulder Surgery Patients

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Background and Aim: Interscalene Brachial Plexus Block (ISBPB) is commonly used for shoulder surgery anesthesia to reduce opioid use and general anesthesia complications. However, it may cause diaphragmatic paresis due to phrenic nerve involvement. This study compares the incidence of hemidiaphragmatic paralysis and the frequency of side effects—including hemodynamic changes and postoperative complications—between the Extrafascial (ExF) and Intrafascial (InF) approaches for ISBPB using reduced anesthetic volume. The aim is to assess whether the ExF approach may be preferable in patients with reduced cardiopulmonary reserve (eg, COPD or heart failure).

Methods: A retrospective study was conducted at Federico II University in Naples, Italy, including 61 patients undergoing shoulder surgery from January 2024 to October 2024. About 33 patients received ExF while 28 received InF ISBPB, all with Ropivacaine 0.5% (10 mL), Mepivacaine 2% (5 mL), and Dexamethasone (4 mg). The primary outcome was the incidence of hemidiaphragmatic paralysis, evaluated via ultrasound pre and 30 minutes after the block by assessing diaphragm excursion, thickness, and thickening fraction. Secondary outcomes included intraoperative hemodynamic changes and postoperative complications: pain (NRS), analgesic/antiemetic requests, PONV, pruritus, shivering, anxiety, and discomfort.

Results: The TF significantly decreased after the block in both groups ($p < 0.001$), with no intergroup. Diaphragm paralysis occurred in 28 patients in each group ($p = 0.093$), without clinical respiratory effects. The InF group had more hypotension episodes (100% vs 30.3%, $p = 0.002$), and significantly lower mean and systolic blood pressure values at 1 and 2 hours after-block. No cases of anxiety, pruritus, shivering, or discomfort were observed. NRS was higher in the InF group at 6 hours but lower at 12 and 24 hours. Analgesic/antiemetic needs were similar; PONV was more frequent in the ExF.

Conclusion: Both approaches resulted in similar rates of hemidiaphragmatic paralysis. However, ExF was associated with fewer hemodynamic effects, suggesting potential benefit in high-risk cardiopulmonary patients.

Keywords: brachial plexus block, interscalene block, diaphragmatic paralysis, analgesia, regional anesthesia

Introduction

Over the past decade, the use of the Interscalene Brachial Plexus Block (ISBPB) in shoulder surgery has significantly increased, becoming a viable approach for regional anesthesia in these procedures due to its effectiveness in reducing opioid

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consumption and complications associated with general anesthesia.[1] Arthroscopic and open shoulder surgeries have increased in volume in many countries.[2] In the United States from 2004 to 2009, out of 23,096 cases of shoulder stabilization, 84% (19,337) were arthroscopic procedures, and 16% (3759) were open.[3] In 2012, the incidence rate of shoulder arthroplasty was 20 procedures per 10,000 people, a 2.8-fold increase over the past decade internationally.[4] Performing an ISBPB is not always safe for every patient category, in fact this approach can lead to complications, including a high incidence of unilateral hemidiaphragmatic paresis caused by spread of Local Anesthetic (LA) around the phrenic nerve and the anteromedial surface of the anterior scalene muscle.[5,6] While unilateral hemidiaphragmatic palsy is generally well tolerated by healthy individuals and symptomatic patients are indeed few, the condition may pose difficulties for patients with preexisting respiratory dysfunction, such as Chronic Obstructive Pulmonary Disease (COPD), Obstructive Sleep Apnea (OSA), obesity, or some neurological conditions.[6,7] The incidence of hemidiaphragmatic paralysis after ISBPB can be accurately assessed with ultrasound, which enables direct study of the diaphragm's structural and functional components, including excursion, thickness, and diaphragmatic Thickness Fraction (TF), at the patient's bedside.[8–10] In recent years, diaphragm-sparing techniques have been proposed to preserve diaphragmatic function and enhance safety in patients with respiratory or chest wall disease, including superior trunk block, supraclavicular brachial plexus block, suprascapular or axillary nerve block and Extrafascial (ExF) injection for ISBPB.[11] We hypothesized that an ExF injection of ISBPB is associated with a lower incidence of unilateral hemidiaphragm paralysis. Although previous studies have compared extrafascial and interfascial approaches, most employed larger volumes of local anesthetic—typically 20 mL or more. Our study is among the first to evaluate both techniques using a reduced volume of 15 mL, highlighting their safety and effectiveness in patients at risk of respiratory or hemodynamic compromise. The aim of our study was to evaluate the incidence of hemidiaphragmatic paralysis, intraoperative hemodynamic changes, and postoperative complications, including pain control, by comparing ExF and InF ISBPB approaches.

Materials and Methods

This study was a Level III monocentric before-and-after[12] retrospective comparative analysis conducted at the Department of Neurosciences, Reproductive, and Odontostomatological Sciences at Federico II University in Naples, Italy. The Federico II University's ethics committee was consulted and confirmed that formal ethical approval was not required, as the study involved a retrospective analysis of anonymized data collected during routine clinical care. Data anonymization was ensured through a systematic algorithm which involved removal of all personal identifiers (such as names, dates of birth, and ID numbers), and replacement with unique study codes. The anonymized dataset was securely stored in a password-protected system accessible only to the research team. All patients provided informed consent for anesthesia and agreed to the anonymous use of their data for scientific purposes. Data were collected from patients undergoing shoulder surgery between January 2024 and October 2024 at our institution, as part of routine clinical practice, was archived by the department. These records were anonymized and stored in a password-protected computerized database using MS Office Excel 2007 (Microsoft, Redmond, WA, USA). All procedures adhered to the 1964 Declaration of Helsinki and subsequent amendments or comparable ethical standards and followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement guidelines.

Inclusion/Exclusion Criteria

The inclusion criteria were as follows:

- Adult patients (≥18 years old);
- American Society of Anesthesiologists-Physical Status (ASA-PS) of I–IV; ASA III and IV patients were included to reflect the real-world clinical population. Each case was evaluated individually by the anesthesiology team to ensure safe regional anesthesia administration.
- Patients undergoing open or arthroscopic shoulder surgery using ISBPB and sedation;
- Patients whose medical records were fully accessible.

The exclusion criteria were:

- Patients with mental disorders;
- Block refusal;
- LA allergy;
- Patients with neuropathic disease of the affected limb;
- Pregnancy;
- Patients with history of neck surgery;
- Patients undergoing general anesthesia

Study Population

After applying the inclusion/exclusion criteria, 7 patients out of 68 were excluded (another type of peripheral nerve block or general anesthesia were performed, data in medical records were not accessible, LA allergy), leaving 61 patients eligible for the study (Figure 1).

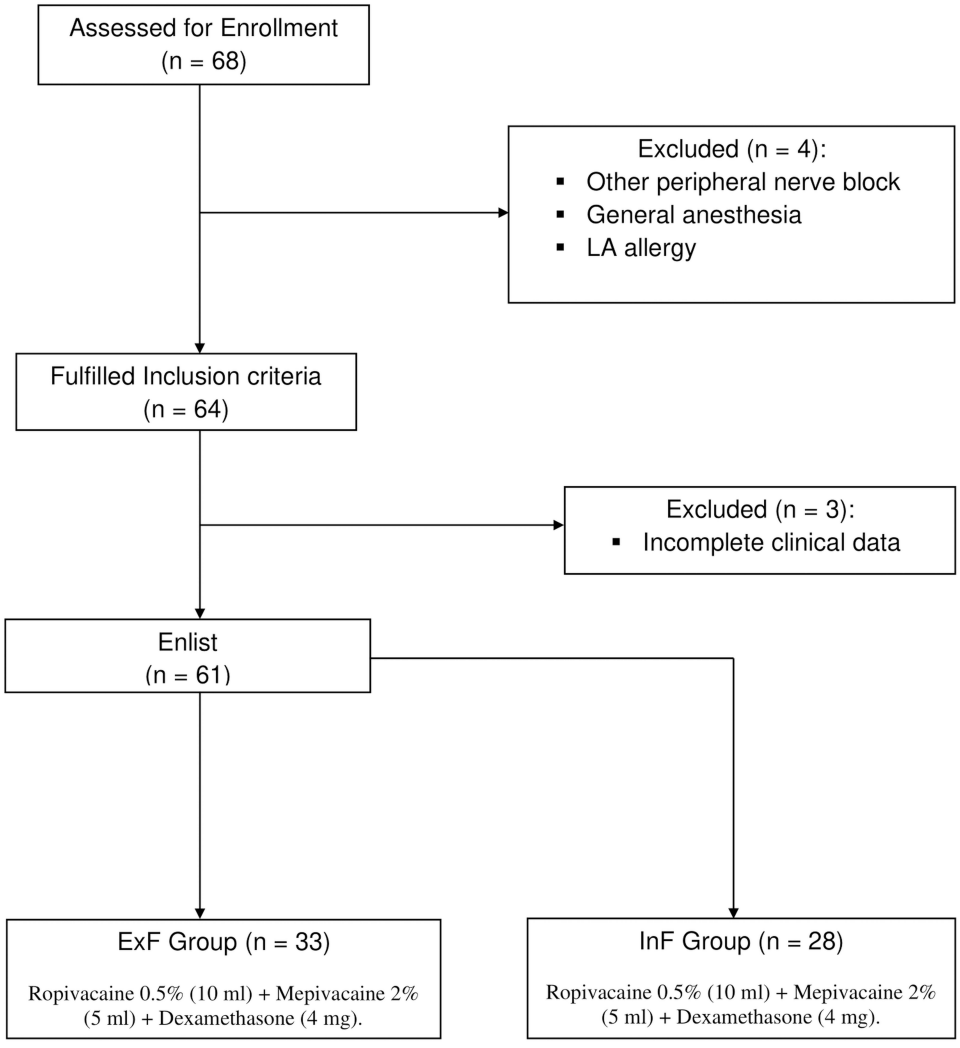

Figure 1 Flowchart of the study. (n =): number of subjects in each group. Ropivacaine 0.5% (10 mL) + Mepivacaine 2%(5 mL) + Dexamethasone (4 mg): anesthesiologic mixture used for both group.
Abbreviations: mL, milliters; mg, milligrams; LA, Local Anesthetic; InF, Intrafascial; ExF, Extrafascial.

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Anesthesiologic Management

In the operating room, venous access was obtained (18–16 Gauge). Pantoprazole 40 mg and prophylactic antibiotics (cefazolin 1–2 g IV or clindamycin 600 mg IV for allergic patients) were administered intravenously 30 minutes prior to the incision. Midazolam (0.01–0.03 mg/kg IV) was used for premedication to enhance patient compliance and comfort. The sedation level was monitored using the Richmond Agitation-Sedation Scale (RASS) intraoperatively and postoperatively. Postoperative Nausea and Vomiting (PONV) prophylaxis followed the Apfel score and the 2020 Fourth Consensus Guidelines for the Management of PONV.[13] During the procedure, monitoring included Electrocardiogram (ECG), Heart Rate (HR), Peripheral Capillary Oxygen Saturation (SpO_2) measured by pulse oximetry, Body Temperature (°C), and Continuous Non-Invasive Blood Pressure (NIBP) measured every 5 minutes. Episodes of hemodynamic instability (Mean Blood Pressure (MBP) < 60 mmHg; Systolic Blood Pressure (SBP) < 90 mmHg or > 20% decrease from baseline; HR < 60 bpm) and surgical times were recorded. Hypotensive events were treated according to the protocol with intravenously crystalloids and/or ephedrine. Intravenous crystalloids were administered intraoperatively at 3 mL/kg/hour. After surgery, patients remained in the PACU for approximately 30 minutes before being transferred to the ward. Side effects such as pruritus, drowsiness, PONV, shivering, and anxiety were monitored during and after surgery. Treatment followed standard hospital protocols, including antihistamines for pruritus and ondansetron for PONV if required.

Peripheral oxygen saturation (SpO_2) was continuously monitored throughout the perioperative period. In cases of desaturation (SpO_2 < 94%), supplemental oxygen was administered via nasal cannula (2–4 L/min) as clinically indicated during the block procedure and in the immediate postoperative phase.

Ultrasound-Guided ISBPB

ISBPB was performed in a dedicated "block room" before surgery, using a standardized anesthesiological mixture consisting of 15 mL with Ropivacaine 0.5% (10 mL), Mepivacaine 2% (5 mL), and Dexamethasone (4 mg). Patients were positioned supine, heads rotated away from the side to be blocked. The skin was disinfected with 2% chlorhexidine solution in 70% isopropyl alcohol. A high-frequency linear probe transducer (13–6 MHz, Sonosite Europe) was placed in the transverse plane in the supraclavicular fossa to identify the subclavian artery, which appears as a pulsatile, hypoechoic structure. The trunks and their divisions were identified lateral to the artery. When visualized in the short axis, these structures appeared as rounded, oval hypoechoic shapes, typically numbering between five and seven, resembling a characteristic grape cluster. Using the traceback technique, the ultrasound probe was advanced in a caudal-to-cranial direction along Grossi's anesthetic line, extending from the apices of the scalene muscles to the point where the axillary artery becomes palpable in the axillary cavity. This method enabled retrograde identification of the brachial plexus by directly visualizing the nerve roots as they emerged from the transverse processes. The C5, C6, and C7 roots appeared as hypoechoic, rounded structures aligned vertically between the anterior and middle scalene muscles. Their identification was confirmed by dynamic cranial tracing from the supraclavicular fossa to their origins at the respective transverse processes. Notably, C7 was classified as such only when its emergence from the spinal foramen was clearly visualized. Color Doppler imaging was employed to distinguish neural from vascular structures and enhance anatomical precision. The use of color Doppler was used to identify and avoid vascular structures, as recommended. With a latero-medial approach and using the in-plane technique, a 21-gauge needle that is 50 mm long (Pajunk) was inserted at this level.

In the ExF Group, the needle tip was positioned lateral to brachial plexus sheath, equidistant from C5 and C6 nerve roots, without penetrating the paravertebral fascia (Figure 2). In the InF Group, the needle was placed within the brachial plexus sheath, between C5 and C6 nerve roots (Figure 3). Sensory and motor block assessments were initiated 10 minutes post-injection and evaluated using the Hollmen scale and the modified Bromage scale. Assessments were repeated as necessary until an adequate anesthetic level for surgical intervention was confirmed. Surgical procedures were initiated only upon achieving a complete block (Hollmen score of 4; modified Bromage score of 0), with patients positioned in the beach-chair position. If necessary, subcutaneous infiltration with 1–2% lidocaine was performed to ensure complete cutaneous anesthesia, taking into account the innervation of the surgical field by the superficial cervical plexus.

All blocks and diaphragmatic ultrasound assessments were performed by anesthesiologists with over three years of experience using a Sonosite Edge II ultrasound machine with a 13–6 MHz linear and 2–6 MHz curvilinear probe.

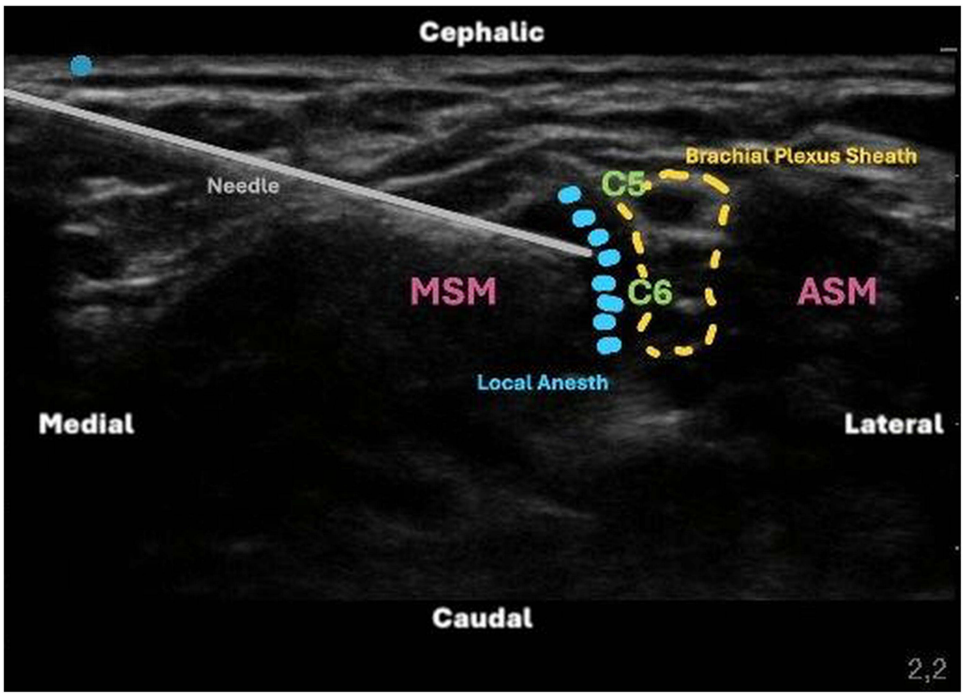

Figure 2 Ultrasound-guided ExF approach for ISBPB. The needle tip is positioned lateral to the brachial plexus sheath, without penetrating the paravertebral fascia. Yellow dashed lines delineate the brachial plexus sheath between the C5 and C6 nerve roots. Blue dots mark the site of local anesthetic injection administered outside this sheath. **Abbreviations**: MSM, Middle Scalene Muscle; ASM, Anterior Scalene Muscle; Local Anesth, Local Anesthetic.

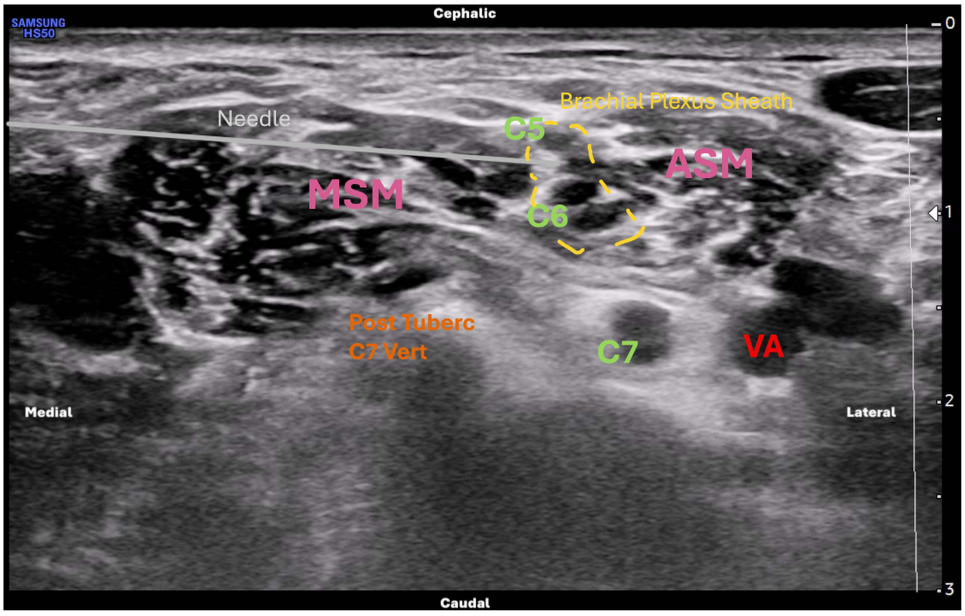

Figure 3 Ultrasound-guided InF approach for ISBPB: the needle tip placement is within the brachial plexus sheath between C5 and C6 nerve roots (yellow dashed lines). **Abbreviations**: MSM, Middle Scalene Muscle; ASM, Anterior Scalene Muscle; VA, Vertebral Artery; Post Tuberc C7 Vert, Posterior Tubercle of C7 Vertebra.

Diaphragmatic Assessment

The diaphragmatic function was assessed before and after ISBPB using ultrasound to identify phrenic nerve involvement. A low-frequency curvilinear probe (2–6 MHz) was employed in anterior subcostal approach to measure diaphragmatic excursion in One-Dimensional Ultrasound Mode (M-mode) during quiet and deep breathing. After the positioning of the patient in semi recumbent position (supine with an angle of 45°), the probe is placed on the right midclavicular line

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parallel to the costal margin to visualize the hepatic window. On ultrasound, the diaphragm appeared as a hyperechoic line with movements synchronized with respiration, typically visualized in the acoustic window of the liver and spleen; diaphragmatic excursion was measured by evaluating the amplitude of the motion trace from quiet exhalation to deep inspiration (Figure 4). Complete hemidiaphragmatic paralysis was characterized by a 75% reduction in excursion compared to the pre-ISBPB assessment, while partial paralysis was indicated by a 25% to 75% reduction in excursion relative to the pre-ISBPB measurements. Diaphragmatic thickness was assessed in B-mode ultrasonography at the Apposition Zone, using a high-frequency linear probe at the eighth or ninth intercostal space. Although M-mode is commonly used for excursion, thickness was measured in static B-mode as per current clinical standards. Surrounding the diaphragmatic muscle, a hyperechogenic membrane, representing both the pleural and peritoneal layers was visible (Figure 5). To calculate diaphragmatic thickness, the distance was measured from the pleural membrane to the center of the peritoneal membrane during quiet exhalation, inspiration, and deep inspiration. The average diaphragm thickness is typically between 0.22 cm and 0.28 cm, whereas a paralyzed diaphragm measures between 0.13 cm and 0.19 cm. The following formula has been used for calculating TF: TF = end-inspiration thickness - end-expiration thickness/end-expiration thickness × 100. TF is expressed as a percentage of the end-expiration thickness. In cases of diaphragmatic paralysis, TF ranges from 28% to 96% during inspiration. Conversely, when paralysis is present, TF ranges from −35% to 5%. A TF < 30% indicated paralysis or severe impairment of the diaphragm.

Data Extraction

All data in this study were extracted from medical records.

The population characteristic data obtained were: age; Body Mass Index (BMI, kg/m^2); surgery duration (minutes); ASA-PS; sex; side and surgery type.

Before the block and after 30 minutes in the recovery room, the following data were extracted: diaphragm excursion (cm); diaphragm thickness at end-inspiration and end-expiration (cm); TF (as a proportion); diaphragm excursion

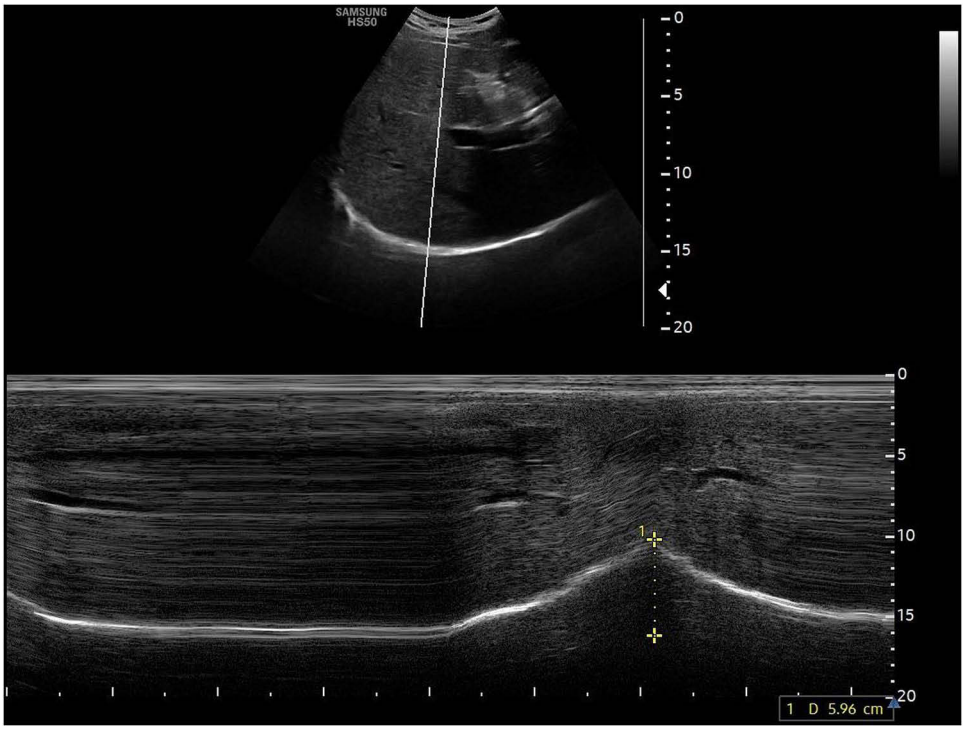

Figure 4 M-mode ultrasound assessment of hemidiaphragmatic excursion via a subcostal approach during deep breathing. After identifying the diaphragm in B-mode, M-mode was activated to record real-time diaphragmatic motion. Calipers were placed at the baseline (end-expiration) and at the peak of inspiration (1) to measure excursion in centimeters.

Abbreviations: B-mode, Brightness Mode; M-mode, Motion Mode.

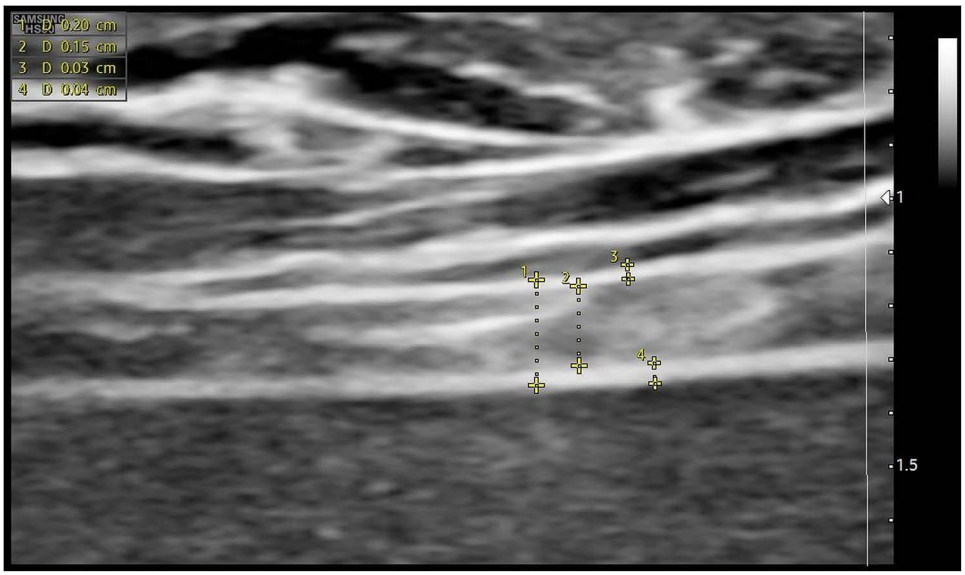

Figure 5 B-mode ultrasound assessment of hemidiaphragmatic thickness. Acquired at the 8th–9th right intercostal space in the zone of apposition (ZOA) with a 10 MHz linear probe. The diaphragm appears as a hypoechoic central layer (2), between two echogenic layers: diaphragmatic pleurae (3) and peritoneum (4). Thickness was measured at end-inspiration (TEI, 1) and end-expiration (TEE, not shown). TF = [(TEI − TEE) / TEE]. 1. TEI. 2. Diaphragm Layer. 3. Pleura Layer. 4. Peritoneum Layer.
Abbreviations: B-mode, Brightness Mode; ZOA, zone of apposition; TEI, thickness at end-inspiration; TEE, thickness at end-expiration; TF, thickening fraction.

variation, SpO_2% with a Fraction Of Inspired Oxygen (FiO_2) of 21%, Hollmen and modified Bromage scales (points) after 10 minutes from block performing.

During the operation, the following data were extracted: HR, SBP, Diastolic Blood Pressure (DBP), MBP at the baseline, after 1 hour, and 2 hours; Richmond Agitation Sedation Scale (RASS); hypotension rate (defined as an MBP lower than 65 mmHg); anxiety rate; nausea and vomiting rate; shivering rate; pruritus rate; patient discomfort rate. Hemodynamic parameters were collected at 1 and 2 hours to detect delayed effects potentially linked to the block technique, minimizing bias due to surgical factors like bleeding, sedation depth, and fluid shifts.

At the end of the surgery, Hollmen and modified Bromage scales data were extracted. We also obtained at the end of the surgery and every 6 hours until 24 hours: RASS, Numerical Rating Scale (NRS); limb mobility restriction; analgesic and antiemetic request; PONV rate. Patients were also monitored for full resolution of the block and the presence of neurological complications such as persistent numbness, weakness, or signs of nerve palsy during the 24-hour observation period.

Statistical Analysis

No formal sample size calculation was performed, as all eligible patients within the specified time frame (January to October 2024) who met the inclusion criteria were retrospectively included in the analysis. The continuous parametric data were presented as mean and standard deviations (SD) and the non-parametric ones as median and interquartile range (IQR) expressed as first and third quartile. The dichotomous variables were presented as absolute and relative frequencies as number and percentage. The parametric continuous data were analyzed with Student's *t*-test, the non-parametric continuous data with the Mann–Whitney *U*-test, and the dichotomous data were analyzed with $\chi 2$ test. The p-value was considered significant if it was less than 0.05. All the calculation were performed with R-studio, based on R, and its packages "rstatix".[14,15]

Results

The patients admitted to final analysis were 61, 28 in InF group and 33 in ExF group.

Table 1 reports the analysis of demographic and anamnestic variables. No differences were between groups. The mean age was comparable (InF 59.71 years ± 17.73 vs ExF 62.79 years ± 9.12), as were ASA-PS, sex, and surgery type

Table 1 Patients Characteristics

N = 61	Group InF (N = 28)	Group ExF (N = 33)	p-value
	Mean (SD)	Mean (SD)	
Age (years)	59.71 (17.73)	62.79 (9.12)	0.412
BMI (kg/m^2)	26.01 (2.41)	25.03 (2.27)	0.080
Surgery duration (minutes)	142.14 (37.6)	146.67 (41.75)	0.657
	N (%)	**N (%)**	**p-value**
ASA-PS			
I	4 (14.28%)	4 (12.12%)	0.052
II	20 (71.42%)	15 (45.45%)	
III	4 (14.28%)	14 (42.42%)	
IV	0 (0%)	0 (0%)	
Sex			
Male	16 (57.14%)	15 (45.45%)	0.513
Female	12 (42.85%)	18 (54.54%)	
Side			
Right	13 (46.43%)	13 (39.4%)	0.769
Left	15 (53.57%)	20 (60.6%)	
Surgery Type			
Prothesis	12 (42.85%)	13 (39.39%)	0.485
Stabilization	4 (14.28%)	5 (15.15%)	
Arthroscopy	12 (42.85%)	15 (45.45%)	

Abbreviations: BMI, Body Mass Index; ASA-PS, America Society of Anesthesiologists-Physical Status; SD, standard deviation.

distribution. The block was performed on the right side for 13 patients in each group, with 46.43% in one group and 60.6% in the other. On the left side, the block was performed in 15 patients from the first group and 20 patients from the second group, resulting in percentages of 53.57% and 60.6%, respectively.

Table 2 shows the diaphragm evaluation pre and 30 minutes after block, SpO_2% with FiO_2 of 21%, sensory and motor block 10 minutes after block performing. The identical mean and SD values for pre-block excursion in both groups were

Table 2 Diaphragm Ultrasound Evaluation Before and After 30 Minutes by Block, Recording Peripherally Saturation (SpO_2%) with Fraction of Inspired Oxygen (FiO_2) of 21%. Sensory and Motor Block Assessment Using Hollmen and Modified Bromage Scale

N = 61	Group InF (N = 28)	Group ExF (N = 33)	p-value
	Mean (SD)	Mean (SD)	
Diaphragm excursion (cm)			
Pre-block	4.65 (0.48)	4.65 (0.48)	0.996
30 minutes after block	0.96 (0.21)	1.09 (0.25)	0.134
p-value	<0.001	<0.001	
Pre-block thickness (cm)			
†At end-inspiration	0.3 (0.05)	0.3 (0.04)	0.994
At end-expiration	0.19 (0.3)	0.2 (0.3)	0.909
After block thickness (cm)			
†At end-inspiration	0.24 (0.04)	0.25 (0.05)	0.117
At end-expiration	0.20 (0.03)	0.21 (0.03)	0.22

(*Continued*)

Table 2 (Continued).

N = 61	Group InF (N = 28)	Group ExF (N = 33)	p-value
	Mean (SD)	Mean (SD)	
TF (proportion)			
Pre-block	0.49 (0.06)	0.49 (0.06)	0.939
30 minutes after block	0.19 (0.05)	0.22 (0.07)	0.087
p-value	<0.001	<0.001	
	N (%)	**N (%)**	**p-value**
Diaphragm excursion variation			
Reduction (>75% of the baseline value)	28 (100%)	28 (85.71%)	0.093
Normal Movement	0 (100%)	5 (14.29%)	
Significative TF			
Pre-block	0 (0%)	0 (0%)	*
30 minutes after block	28 (100%)	28 (85.71%)	0.092
	Median (IQR)	**Median (IQR)**	**p-value**
SpO_2% (FiO_2 21%)			
Pre-block	98 (96–98)	98 (97–99)	0.211
30 minutes after block	96 (95–97)	96 (94–96)	0.278
p-value	<0.001	<0.001	
Modified Bromage scale - 10 minutes after block (points)	1 (1–2)	1 (1–2)	0.208
Hollmen scale - 10 minutes after block (points)	3 (2–4)	3 (2–3)	0.44

Notes: *The data were constant. †p < 0.05 between pre and after block for thickness at end-inspiration and end-expiration in each group.
Abbreviations: TF, thickness fraction; FiO_2, fraction of inspired oxygen; SD, standard deviation.

confirmed upon review of raw data and attributed to a homogeneously selected patient cohort with consistent baseline respiratory function Although no significant differences were observed in diaphragm excursion or thickness between groups before and after the block, the similarity in values—especially for thickness—falls within the expected variation range and is consistent with previously published data using reduced local anesthetic volumes, the end-inspiration thickness was higher before block both in InF (0.3 cm ± 0.05 vs 0.24 cm ± 0.04, $p < 0.05$) and in ExF (0.3 cm ± 0.03 vs 0.24 cm ± 0.05, $p < 0.05$) group. Moreover, the TF was lower after the block in InF (0.49 ± 0.06 vs 0.19 ± 0.05, $p<0.001$) and ExF (0.49 ± 0.06 vs 0.22 ± 0.07, $p < 0.001$), with no difference between the groups. About 28 patients had a diaphragm excursion variation >75% in both groups (100% vs 85.72%, $p = 0.093$) with a significant diaphragm paralysis and a TF reduction ≤30% (100% vs 85.72%, $p = 0.093$) 30 minutes after block performing. The diaphragm paralysis impacted equally on SpO2% with higher values before and after the block both in InF (98% IQR 96–98 vs 96% IQR 95–97, $p < 0.001$) and ExF (98% IQR 97–99 vs 96% IQR 94–96, $p < 0.001$) groups, with no difference between InF and ExF groups ($p = 0.211$ for comparison before the block, $p = 0.278$ for comparison after the block). No differences were found in modified Bromage scores (1 point IQR 1–2 vs 1 point IQR 1–2) and Hollmen scores (3 points IQR 2–4 vs 3 points IQR 2–3) comparing InF and ExF groups.

Table 3 indexes the intraoperative evaluation; 24 patients and 28 patients were evaluated at 2 hours for InF and ExF groups, respectively. No differences in HR, SBP, DBP, and MBP were found at baseline between groups. After 1 hour, InF reported a lower SBP (109.57 mmHg ± 11.58 vs 124 mmHg ± 8.97, $p < 0.001$) and MBP (78.71 mmHg ± 7.09 vs 85.51 mmHg ± 10.06, $p = 0.03$) compared to ExF. The trend was confirmed also after 2 hours with an SBP (107.33 mmHg ± 10.19 vs 129 mmHg ± 12.95, $p < 0.001$), DBP (59 mmHg ± 8.17 vs 69 mmHg ± 11.86, $p < 0.001$), and MBP (79.66 ± 8.51 vs 88.6 ± 10.29, $p < 0.001$) in InF compared to ExF. Even if the MBP was not clinically significant, the hypotension was more frequent in InF group (100% vs 30.3%, $p = 0.002$). No difference was found in RASS and no anxiety, nausea and vomiting, shivering, or pruritus occurred in both groups. None of patients reported

Table 3 Intraoperative Evaluation

N = 61**	Group InF (N = 28)	Group ExF (N = 33)	p-value
	Mean (SD)	Mean (SD)	
Baseline			
HR (bpm)	63.28 (8.46)	66.51 (6.01)	0.098
SBP (mmHg)	126.5 (10.26)	132.42 (17.09)	0.101
DBP (mmHg)	71.43 (7.78)	75.36 (8.38)	0.062
MBP (mmHg)	90.1 (7.7)	93.86 (9.28)	0.087
After 1 hour			
HR (bpm)	59.27 (13.32)	61.71 (5.76)§	0.364
SBP (mmHg)	109.57 (11.58)§	124 (8.97)§	<0.001
DBP (mmHg)	63.85 (6.87)§	67 (12.05)§	0.208
MBP (mmHg)	78.71 (7.09)§	85.51 (10.06)§	0.003
After 2 hours			
HR (bpm)	56.33 (10.59)§	54.28 (2.74)§†	0.365
SBP (mmHg)	107.33 (10.19)§	129 (12.95)†	<0.001
DBP (mmHg)	59 (8.17)§†	69 (11.86)†	<0.001
MBP (mmHg)	79.66 (8.51)§	88.60 (10.29)	<0.001
	Median (IQR)	**Median (IQR)**	**p-value**
RASS (points)	−2.0 (−5/-1)	−3.0 (−5.0/-1.0)	0.766
	N (%)	**N (%)**	**p-value**
Side effects and complications			
Hypotension	28 (100%)	10 (30.3%)	0.002
Anxiety	0 (0%)	0 (0%)	¥
Nausea and vomiting	0 (0%)	0 (0%)	¥
Shivering	0 (0%)	0 (0%)	¥
Pruritus	0 (0%)	0 (0%)	¥
Patient discomfort	0 (0%)	0 (0%)	¥

Notes: **The patient that reached the 2 hours of intervention were 24 for InF group and 28 for ExF group. §$p < 0.05$ compared to the same parameter at baseline. †$p < 0.05$ compared to the same parameter after 1 hour. ¥data were practically constant.

Abbreviations: HR, heart rate; bpm, beat per minute; SBP, systolic blood pressure; DBP, diastolic blood pressure; MBP, mean blood pressure; RASS, Richmond agitation-sedation scale; SD, standard deviation; IQR, interquartile range.

intraoperative discomfort. The analysis of HR, SBP, DBP, and MBP showed no difference at the baseline; after 1 hour SBP (109.57 mmHg ± 11.58 vs 124 mmHg ± 12.95, $p < 0.001$) and MBP (78.71 mmHg ± 7.09 vs 85.51 mmHg ± 10.06, $p = 0.003$) were higher in ExF compared to InF; moreover, SBP (107.33 mmHg ± 10.19 vs 129 mmHg ± 12.95, $p < 0.001$), DBP (59 mmHg ± 8.17 vs 69 mmHg ± 11.86, $p < 0.001$), and (79.66 mmHg ± 8.51 vs 88.60 mmHg ± 10.29, $p < 0.001$) reported higher values in ExF group. For comparisons between different times in the same group, see Table 3.

Table 4 shows the comparisons between the blocks performed at the right and left side and the comparisons between the blocks executed at the same side for haemodynamic parameters at different times. Comparing the block performed at the left side, InF showed a lower SBP (108.27 mmHg ± 10.82 vs 121.7 mmHg ± 9.71, $p < 0.001$) and MBP (76.8 mmHg ± 7.03 vs 84.15 mmHg ± 11.72, $p = 0.023$) after 1 hour; moreover, also SBP (106.93 mmHg ± 9.92 vs 123.44 mmHg ± 11.91, $p < 0.001$) and DBP (56.79 mmHg ± 6.91 vs 65.56 mmHg ± 13.7, $p = 0.034$) were lower in InF compared to ExF after 2 hours. No other differences were found in analyzing the blocks performed at the left side. Right InF had a lower SBP at 1 hour (121.7 mmHg ± 9.71 vs 111.8 mmHg ± 12.67, $p < 0.001$), at 2 hours (123.44 mmHg ± 11.92 vs 107.9 mmHg ± 11.08, $p < 0.001$), and a lower DBP (65.56 mmHg ± 13.7 vs 62.1 mmHg ± 9.13, $p = 0.005$) and MBP (84.5 mmHg ± 11.54 vs 80 mmHg ± 7.04, $p < 0.001$) at two hours; no other significative

Table 4 Intraoperative Evaluation of Block Performed at Different Sides

N = 61**	Left			Right		
	InF (N = 28)	ExF (N = 33)	p-value	InF (N = 28)	ExF (N = 33)	p-value
	Mean (SD)	Mean (SD)		Mean (SD)	Mean (SD)	
Baseline						
HR (bpm)	61.27 (7.69)	69.75 (5.93)	0.072	69.75 (5.93)	65.61 (9)	0.500
SBP (mmHg)	126.07 (12.54)	128.6 (13.16)	0.566	128.6 (13.16)	127 (7.26)	0.087
DBP (mmHg)	70.8 (6.66)	74.5 (8.36)	0.155	74.5 (8.36)	72.15 (9.13)	0.203
MBP (mmHg)	89.22 (8.09)	92.02 (7)	0.293	92.02 (7)	91.1 (7.42)	0.156
After 1 hour						
HR (bpm)	59.73 (12.52)	60.2 (5.67)	0.894	60.2 (5.67)	64 (13.82)	0.155
SBP (mmHg)°	108.27 (10.82)	121.7 (9.71)	<0.001	121.7 (9.71)	111.08 (12.67)	<0.001
DBP (mmHg)	61.6 (6.79)	66.15 (13.65)	0.206	66.15 (13.65)	66.46 (6.23)	0.562
MBP (mmHg)	76.8 (7.03)	84.15 (11.72)	0.023	84.15 (11.72)	80.92 (6.75)	0.018
After 2 hours						
HR (bpm)°	55.57 (11.87)	55.25 (2.82)	0.922	55.25 (2.82)	57.4 (9.01)	0.162
SBP (mmHg)°	106.93 (9.92)	123.44 (11.91)	<0.001	123.44 (11.91)	107.9 (11.08)	<0.001
DBP (mmHg)	56.79 (6.91)	65.56 (13.7)	0.034	65.56 (13.7)	62.1 (9.13)	0.005
MBP (mmHg)°	79.43 (6.69)	84.5 (11.54)	0.201	84.5 (11.54)	80 (7.04)	<0.001

Notes:**The patients who reached the 2 hours of intervention were 24 for InF group and 28 for ExF group. °p < 0.05 comparing left ExF and right one. The left one showed higher SBP at 1 and 2 hours, MBP at 2 hours.

Abbreviations: HR, heart rate; bpm, beat per minute; SBP, systolic blood pressure; DBP, diastolic blood pressure; MBP, mean blood pressure; SD, standard deviation; IQR, interquartile range.

results were in the other comparisons. SBP after 1 hour, HR, SBP, and MBP after 2 hours were higher in the right ExF compared to InF ($p < 0.05$).

Tables 5 and 6 represent other outcomes. No differences were found in sensory and motor block after the surgery and the RASS was 0 in all patients. The NRS scores (Table 4) were statistically different between groups (0 points IQR 0–0 vs 0 points IQR 0–0, $p = 0.027$) due to two patients who declared an NRS of 3 points after surgery in the InF group; then the pain was felt higher in the InF group at 6 hours (3 points IQR 3–4 vs 1 point IQR 1–4, $p = 0.049$), and then lower at 12 hours (4 points IQR 3–5.5 vs 5 points IQR 4–7, $p = 0.031$) and 24 hours (4 points IQR 2–5 vs 5 points IQR 3–5, $p = 0.026$) compared to ExF. For comparison of NRS at different times in the same group, see Table 4. According to the trend of NRS scores, no patients

Table 5 Secondary Outcomes at Different Postoperative Times: Sensory and Motor Block After Surgery, Numeric Rate Scale (NRS), Richmond Agitation-Sedation Scale (RASS), Limb Mobility Restriction, and Analgesic Request

N = 61	Group InF (N = 28)	Group ExF (N = 33)	p-value
	Median (IQR)	Median (IQR)	
Hollmen scale at surgery end (points)	3 (2–3)	3 (2–3)	0.699
Modified Bromage scale at surgery end (points)	1 (1–2)	1 (1–1.75)	0.455
RASS (points)			
After surgery	0 (0–0)	0 (0–0)	*
At 6 hours	0 (0–0)	0 (0–0)	*
At 12 hours	0 (0–0)	0 (0–0)	*
At 18 hours	0 (0–0)	0 (0–0)	*
At 24 hours	0 (0–0)	0 (0–0)	*
p-value	*	*	

(*Continued*)

Table 5 (Continued).

N = 61	Group InF (N = 28)	Group ExF (N = 33)	p-value
	Median (IQR)	Median (IQR)	
NRS (points)			
After surgery	0 (0–0)[£]	0 (0–0)	0.027
At 6 hours	3 (3–4)[θ]	1 (1–4)[θ]	0.049
At 12 hours	4 (3–5.5)[θ]	5 (4–7)[θ]	0.031
At 18 hours	5.5 (3–6.5)[θ]	5 (5–6.5)[Δ]	0.360
At 24 hours	4 (2–5)[θ]	5 (3–5)[θ]	0.026
p-value	<0.001	<0.001	
	N (%)	**N (%)**	**p-value**
Limb mobility restriction			
After surgery	28 (100%)	33 (100%)	*
At 6 hours	28 (100%)	33 (100%)	*
At 12 hours	28 (100%)	33 (100%)	*
At 18 hours	28 (100%)	33 (100%)	*
At 24 hours	28 (100%)	28 (84.84%)	0.092
Analgesic request			
After surgery	0 (0%)	0 (0%)	*
At 6 hours	0 (0%)	0 (0%)	*
At 12 hours	4 (12.12%)	3 (9.09%)	1
At 18 hours	12 (36.36%)	13 (39.39%)	1
At 24 hours	4 (12.12%)	0 (0%)	0.084

Notes: *The data were practically constant. [£]2 patients declared a NRS scores of 3 points after surgery. [θ]$p < 0.05$ compared to the previous times. [Δ]$p < 0.05$ compared to pain after surgery and after 6 hours.
Abbreviations: RASS, Richmond agitation-sedation scale; NRS,numerical rating scale; SD, standard deviation; IQR, interquartile range.

Table 6 Secondary Outcomes at Different Postoperative Times: PONV and Antiemetic Request Rates

N = 61	Group InF (N = 28)	Group ExF (N = 33)	p-value
	N (%)	N (%)	
PONV rate			
After surgery	0 (0%)	0 (0%)	*
At 6 hours	0 (0%)	9 (27.27%)	0.008
At 12 hours	0 (0%)	9 (27.27%)	0.008
At 18 hours	0 (0%)	9 (27.27%)	0.008
At 24 hours	0 (0%)	0 (0%)	*
Antiemetic request			
After surgery	0 (0%)	0 (0%)	*
At 6 hours	0 (0%)	0 (0%)	*
At 12 hours	0 (0%)	0 (0%)	*
At 18 hours	0 (0%)	0 (0%)	*
At 24 hours	0 (0%)	0 (0%)	*

Note: *The data were practically constant.
Abbreviation: PONV, postoperative nausea and vomiting.

requested analgesic (Table 4) in the first 6 hours; the major request was found at 18 hours with comparable rate (36.36% vs 39.39%, p = 1). Despite slightly higher NRS scores at 24 hours in the ExF group, analgesic requests remained comparable, possibly due to differences in pain perception or the use of background multimodal analgesia. Even if PONV rate (Table 5) was

equally higher in ExF at 6, 12, and 18 hours (27.27% vs 0%, p = 0.008), no patients requested antiemetic (Table 5) at any time of evaluation in both ExF and InF groups. Although patient discomfort and shivering were predefined outcomes, no occurrences were recorded during the study period, thus they are not discussed in the results. Although discomfort, pruritus, and shivering were predefined secondary outcomes, no events were reported in either group, which explains their absence in the data tables.

Discussion

This study found both InF and ExF approaches resulted in a significant reduction in diaphragmatic excursion and TF, with no statistically significant difference between the groups. These findings indicate that reducing the LA volume to 15 mL did not mitigate the risk of phrenic nerve involvement, regardless of the approach. Despite the high rate of diaphragm paralysis in both groups, no patient developed clinically relevant respiratory symptoms, and SpO_2 remained stable throughout. However, a key distinction emerged in hemodynamic effects: hypotensive episodes occurred significantly more frequently in the InF group, supporting potential advantages of the ExF approach in patients with limited cardiovascular reserve. Indeed, ExF showed higher values of blood pressure, especially at 2 hours. Postoperatively, InF initially reported higher pain at 6 hours but less pain at later time points compared to the ExF; nonetheless, overall analgesic consumption remained similar between groups. This apparent paradox—higher hemodynamic instability and pain at 6 hours in the InF group—may suggest a partial or uneven spread of local anesthetic, potentially including unintended epidural or intrathecal diffusion. While such spread could contribute to hypotension, it may not necessarily enhance block effectiveness uniformly, particularly if the analgesic distribution does not fully involve all target nerves. Moreover, the greater sympathetic blockade might be disproportionate to sensory block quality, which could explain the transient increase in pain perception at the early postoperative stage. Interestingly, despite higher PONV rates in the ExF, no patients required antiemetic therapy. No cases of prolonged sensory or motor block, nor signs of nerve injury, were observed during the 24-hour follow-up in either group. Both techniques, InF and ExF, appear feasible for clinical use, albeit with distinct hemodynamic and postoperative recovery profiles, suggesting a tailored approach to patient management based on individual clinical needs.

ISBPB is considered the gold-standard analgesic technique for shoulder surgery. It provides effective postoperative pain relief, leading to lower pain scores, reduced opioid consumption and decreased incidence of PONV.[16]

Although minor complications such as Horner's syndrome, laryngeal nerve palsy, and hypotensive bradycardic events—often linked to sympathetic blockade or anesthetic spread to adjacent neural structures—are frequently reported after ISBPB, our study was not designed or powered to assess these outcomes.[17–19] Their brief mention serves to contextualize the broader safety profile of ISBPB, but a detailed analysis falls outside the scope of our primary focus on diaphragmatic and hemodynamic effects.

In our analysis, hemodynamic instability events were found in 100% of patients undergoing ISBPB with an InF approach and in 30% of those treated with an ExF. The hemodynamic instability that occurs after the performance of ISBPB in shoulder surgery would appear to have no precise etiopathogenesis; there are different hypotheses that could explain the hypotensive and bradycardic effects typically seen in these patients.[20,21] One hypothesis suggested that incidental block of the sympathetic chain or stellate ganglion may influence autonomic function; another theory proposed that block of the spinal nerves supplying the sternocleidomastoid muscle (C2-C4) could affect the carotid sinus baroreceptor reflex arc, leading to vagal stimulation. Additionally, frequent neck turning and arm traction on the shoulder, exacerbated by neck swelling due to LA during the ISBPB, may result in direct manipulation of the carotid sinus.

The sitting position is commonly utilized in shoulder surgery to minimize the heavy traction forces. However, this position has been associated with an increased risk of complications, including hypotensive and bradycardic events, with reported incidences ranging from 13% to 28%.[22–24] Furthermore, Fritsch et al in their cadaver study evaluated the spread of LA at the level of the contralateral cervical roots, finding that after InF injection there was LA migration through the epidural space, as indicated by contrast enhancement; in the ExF injection, instead, no LA migration into the epidural space occurred. In fact, the possibility of inadvertent passage of anesthetic solution into the contralateral intrathecal space in the InF approach cannot be ruled out, given by the anatomical continuity between the epineurium and dura mater surrounding the spinal roots, which are immersed in cerebrospinal fluid. According to these discoveries, Fritsch et al suggested a reduction of the LA volume to avoid epidural diffusion of drug in the InF approach.[25]

In the literature, ISBPB has been reported to cause phrenic nerve involvement leading to diaphragmatic hemiparesis in 100% of patients at the typical LA volumes used in clinical practice (15–20 mL).[5–7,26] Our study found the same incidence of

hemidiaphragmatic paralysis, regardless of whether the InF or ExF approach was used. Consistent with our findings, Ayyanagouda et al, in a double-blind randomized clinical trial, reported no significant differences between the two techniques in terms of sensory-motor block efficacy and postoperative pain control. However, in contrast to our results, they observed reduced phrenic nerve involvement with the ExF approach using 20 mL of 0.5% ropivacaine.[5] This finding was further supported by a meta-analysis by Sharapi et al, which demonstrated the superiority of the extrafascial injection in reducing the incidence of hemidiaphragmatic paresis and preserving respiratory function.[27]

Discovering new technical approaches that reduce patients discomfort and complication rates should be a priority goal in this field, recognizing that continuous anesthesia techniques remain the most effective choice.[28–30]

The chosen volume of 15 mL for the LA is regarded as the standard dosage for anesthesia in shoulder surgery. A randomized, double-blind controlled trial by Renard et al demonstrated that reducing the anesthetic volume to 10 mL decreased the incidence of diaphragmatic paralysis; however, this reduction was associated with decreased analgesia and increased postoperative morphine consumption.[31] Conversely, Oliver-Fornies et al conducted a randomized, double-blind controlled trial that showed a reduction in phrenic nerve involvement with a lower LA volume, without compromising postoperative analgesia.[32] Further disagreement emerges from a randomized controlled study by Sinha et al which found no reduction in phrenic nerve involvement following ISBPB when the LA volume was reduced from 20 mL to 10 mL.[33] Given these findings, further studies may be necessary to determine whether reducing LA volume can effectively minimize phrenic nerve involvement in ISBPB performed with an ExF approach.

Initially, ISBPB in our department was always performed with an InF approach; however, in our experience, we found a symptomatic phrenic nerve block more often in patients with preexisting respiratory disease. These events prompted us to reflect on the ExF approach, so we decided to perform ISBPB without crossing the paravertebral fascia.

Our study data still included the administration of dexamethasone perineurally; we currently administer dexamethasone intravenously, according to scientific evidence showing superimposable effects regarding the duration of analgesia after administration of dexamethasone perineurally or intravenously.[34–36]

This study has several limitations. First, the retrospective design should be taken into account. Second, the small sample size of patients may lead to a type II error, limiting the ability to detect differences between groups; this suggests the need for further research involving larger cohorts of patients to validate our findings. Third, patients were evaluated by different medical teams during the intraoperative and postoperative phases. Fourth, injection pressure was not monitored, which is noteworthy since elevated pressure may increase the risk of intrafascial spread and phrenic nerve involvement. Fifth, Horner's syndrome was not systematically assessed, though no clinical signs were observed; its potential hemodynamic impact warrants future investigation. Finally, diaphragmatic function was assessed only at two time points—pre-block and 30 minutes post-block—limiting our ability to determine the precise duration or recovery timeline of hemidiaphragmatic paralysis, which is clinically relevant in patients with reduced respiratory reserve. Additionally, measurements of diaphragmatic excursion and thickness may have been influenced by operator-dependent variability and unaccounted pre-existing pathological conditions within the study population. Given the retrospective design and absence of extended follow-up, recovery to baseline diaphragmatic function could not be evaluated. These limitations underscore the need for future prospective studies to include serial assessments over time, enroll patients with known pulmonary compromise for subgroup analysis, and estimate sample sizes based on the expected incidence of diaphragmatic paralysis.

Conclusion

Our study found a similar incidence of hemidiaphragmatic paralysis with both the InF and ExF ISBPB approaches, suggesting no clear advantage in terms of diaphragmatic preservation. However, the ExF technique was associated with a more favorable hemodynamic profile, with significantly less hypotension observed compared to the InF group. This may make the ExF approach more appropriate for patients at risk of hemodynamic compromise, such as the elderly or those with limited cardiovascular reserve. Nevertheless, given the limited sample size and methodological constraint, these findings should be interpreted with caution. Future research should focus on optimizing block techniques by evaluating lower volumes of local anesthetic (eg, <10 mL) and comparing different agents, such as bupivacaine and ropivacaine, within both approaches. Prospective, randomized studies with larger sample sizes are needed to validate these preliminary observations and better define their clinical impact.

Abbreviations

ISBPB, Interscalene Brachial Plexus Block; LA, Local Anesthetic; COPD, Chronic Obstructive Pulmonary Disease; OSA, Obstructive Sleep Apnea; TF, Thickness Fraction; ExF, Extrafascial; InF, Intrafascial; ASA-PS, American Society of Anesthesiologists-Physical Status; PONV, Postoperative Nausea and Vomiting; ECG, Electrocardiogram; HR, Heart Rate; °C, Body Temperature; NIBP, Non Invasive Blood Pressure; MBP, Mean Blood Pressure; SBP, Systolic Blood Pressure; PACU, Post-Anesthesia Care Unit; BMI, Body Mass Index Kg/m^2; FiO_2, Fraction of Inspired Oxygen; DBP, Diastolic Blood Pressure; RASS, Richmond Agitation Sedation Scale; NRS, Numerical Rating Scale; SD, Standard Deviations; IQR, Interquartile Range; LAST, Local Anesthetic Syndrome Toxicity.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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References

1. Lee BH, Qiao WP, McCracken S, Singleton MN, Goman M. Regional anesthesia techniques for shoulder surgery in high-risk pulmonary patients. *J Clin Med*. 2023;12:3483.
2. Villatte G, Erivan R, Barth J, Bonnevialle N, Descamps S, Boisgard S. Progression and projection for shoulder surgery in France, 2012-2070: epidemiologic study with trend and projection analysis. *Orthop Traumatol Surg Res*. 2020;106(6):1067–1077. Epub 2020 Aug 27. doi:10.1016/j.otsr.2020.04.019
3. Zhang AL, Montgomery SR, Ngo SS, Hame SL, Wang JC, Gamradt SC. Arthroscopic versus open shoulder stabilization: current practice patterns in the United States. *Arthroscopy*. 2014;30(4):436–443. Epub 2014 Feb 20. doi:10.1016/j.arthro.2013.12.013
4. Lübbeke A, Rees JL, Barea C, Combescure C, Carr AJ, Silman AJ. International variation in shoulder arthroplasty. *Acta Orthop*. 2017;88(6):592–599. doi:10.1080/17453674.2017.1368884
5. Ayyanagouda B, Hosalli V, Kaur P, Ambi U, Hulkund SY. Hemi-diaphragmatic paresis following extrafascial versus conventional intrafascial approach for interscalene brachial plexus block: a double-blind randomised, controlled trial. *Indian J Anaesth*. 2019;63(5):375–381. doi:10.4103/ija.IJA_69_19
6. Urmey WF, McDonald M. Hemidiaphragmatic paresis during interscalene brachial plexus block: effects on pulmonary function and chest wall mechanics. *Anesth Analg*. 1992;74(3):352–357. doi:10.1213/00000539-199203000-00006
7. Kim KS, Ahn JH, Yoon JH, Ji HT, Kim IS. Hemidiaphragmatic paresis following interscalene brachial plexus block with 2-point injection technique. *Pain Phys*. 2021;24(8):507–515. PMID: 34793637.
8. Testa A, Soldati G, Giannuzzi R, Berardi S, Portale G, Gentiloni Silveri N. Ultrasound M-mode assessment of diaphragmatic kinetics by anterior transverse scanning in healthy subjects. *Ultrasound Med Biol*. 2011;37(1):44–52. doi:10.1016/j.ultrasmedbio.2010.10.004
9. Sarwal A, Walker FO, Cartwright MS. Neuromuscular ultrasound for evaluation of the diaphragm. *Muscle Nerve*. 2013;47(3):319–329. doi:10.1002/mus.23671
10. Yao X-Y, Li H-M, Sun B-W, et al. Ultrasound assessment of diaphragmatic dysfunction in non-critically ill patients: relevant indicators and update. *Front Med*. 2024;11:1389040. doi:10.3389/fmed.2024.1389040
11. Kang R, Ko JS. Recent updates on interscalene brachial plexus block for shoulder surgery. *Anesth Pain Med*. 2023;18(1):5–10. doi:10.17085/apm.22254
12. Sedgwick P. Before and after study designs. *BMJ*. 2014;349:g5074. doi:10.1136/bmj.g5074
13. Gan TJ, Belani KG, Bergese S, et al. Fourth consensus guidelines for the management of postoperative nausea and vomiting. *Anesth Analg*. 2020;131(2):411–448. doi:10.1213/ANE.0000000000004833
14. Wallace BC, Dahabreh IJ, Trikalinos TA, Lau J, Trow P, Schmid CH. Closing the gap between methodologists and end-users: r as a computational back-end. *J Stat Soft*. 2012;49(5):1–5. doi:10.18637/jss.v049.i05
15. Kassambara A. rstatix: pipe-friendly framework for basic statistical tests. 2023. Available from: https://rpkgs.datanovia.com/rstatix/. Accessed September 12, 2025.

16. Warman P, Nicholls B. Ultrasound-guided nerve blocks: efficacy and safety. *Best Pract Res Clin Anaesthesiol*. 2009;23(3):313–326. doi:10.1016/j.bpa.2009.02.004
17. Seltzer JL. Hoarseness and Horner's syndrome after interscalene brachial plexus block. *Anesth Analg*. 1977;56(4):585–586. doi:10.1213/00000539-197707000-00033
18. Nimier M, Berger JL, Desmonts JM. Paralysie récurrentielle et syndrome de Claude Bernard-Horner après blocage interscalénique du plexus brachial [Recurrent nerve paralysis and Claude Bernard-Horner syndrome following an interscalene block of the brachial plexus]. *Ann Fr Anesth Reanim*. 1986;5(4):456–457. French. doi:10.1016/s0750-7658(86)80020-x
19. Brull R, McCartney CJL, Sawyer RJ, von Schroeder HP. The indications and applications of interscalene brachial plexus block for surgery about the shoulder. *Acute Pain*. 2004;6(2):57–77. ISSN 1366-0071. doi:10.1016/j.acpain.2004.04.002
20. Campagna JA, Carter C. Clinical relevance of the Bezold-Jarisch reflex. *Anesthesiology*. 2003;98(5):1250–1260. doi:10.1097/00000542-200305000-00030
21. Song SY, Roh WS. Hypotensive bradycardic events during shoulder arthroscopic surgery under interscalene brachial plexus blocks. *Korean J Anesthesiol*. 2012;62(3):209–219. doi:10.4097/kjae.2012.62.3.209
22. Seo KC, Park JS, Roh WS. Factors contributing to episodes of bradycardia hypotension during shoulder arthroscopic surgery in the sitting position after interscalene block. *Korean J Anesthesiol*. 2010;58(1):38–44. doi:10.4097/kjae.2010.58.1.38
23. Simeoforidou M, Vretzakis G, Chantzi E, et al. Effect of interscalene brachial plexus block on heart rate variability. *Korean J Anesthesiol*. 2013;64(5):432–438. Epub 2013 May 24. doi:10.4097/kjae.2013.64.5.432
24. Nelson M, Reens A, Reda L, Lee D. Profound prolonged bradycardia and hypotension after interscalene brachial plexus block with bupivacaine. *J Emerg Med*. 2018;54(3):e41–e43. Epub 2017 Dec 30. doi:10.1016/j.jemermed.2017.12.004
25. Fritsch G, Hudelmaier M, Danninger T, Brummett C, Bock M, McCoy M. Bilateral loss of neural function after interscalene plexus blockade may be caused by epidural spread of local anesthetics: a cadaveric study. *Reg Anesth Pain Med*. 2013;38(1):64–68. doi:10.1097/AAP.0b013e318277a870
26. Campbell AS, Johnson CD, O'Connor S. Impact of peripheral nerve block technique on incidence of phrenic nerve palsy in shoulder surgery. *Anesthesiol Res Pract*. 2023;2023:9962595. doi:10.1155/2023/9962595
27. Sharapi M, Yassin M, Arafeh Y, Afifi E, El-Samahy M, Thomas J. Efficacy and safety of extrafascial injection versus intrafascial injection for interscalene brachial plexus block: a systematic review and meta-analysis. *Minerva Anestesiol*. 2024;90(6):550–560. doi:10.23736/S0375-9393.23.17807-2
28. Sepolvere G, Tedesco M, Cibelli M, et al. Technical report on the new ultrasound lateral mid-shaft approach to the sciatic nerve: a never-ending story. *Medicina*. 2025;61(1):100. doi:10.3390/medicina61010100
29. Coviello A, Bernasconi A, Balato G, et al. Positioning the catheter tip anterior or posterior to the saphenous nerve in continuous adductor canal block: a mono-centric retrospective comparative study. *Local Reg Anesth*. 2022;15:97–105. doi:10.2147/LRA.S383601
30. Litz RJ, Feigl GC, Radny D, Weiß T, Schwarzkopf P, Mäcken T. Continuous interscalene brachial plexus blocks: an anatomical challenge between scylla and charybdis? *Medicina*. 2024;60(2):233. doi:10.3390/medicina60020233
31. Renard Y, Grape S, Gonvers E, Rossel JB, Goetti P, Albrecht E. Respiratory impact of local anaesthetic volume after an interscalene brachial plexus block with an extrafascial injection: a randomised controlled double-blinded trial. *Br J Anaesth*. 2025;23:S0007–0912(24)00752–9. doi:10.1016/j.bja.2024.12.010
32. Oliver-Fornies P, Ortega Lahuerta JP, Gomez Gomez R, et al. Diaphragmatic paralysis, respiratory function, and postoperative pain after interscalene brachial plexus block with a reduced dose of 10 mL levobupivacaine 0.25% versus a 20 mL dose in patients undergoing arthroscopic shoulder surgery: study protocol for the randomized controlled double-blind REDOLEV study. *Trials*. 2021;22(1):287. doi:10.1186/s13063-021-05216-6
33. 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(1):17–20. doi:10.1097/aap.0b013e3182030648
34. Desai N, Pararajasingham S, Onwochei D, Albrecht E. Comparison of intravenous versus perineural dexamethasone as a local anaesthetic adjunct for peripheral nerve blocks in the lower limb: a meta-analysis and systematic review. *Eur J Anaesthesiol*. 2024;41(10):749–759. doi:10.1097/EJA.0000000000002038
35. Albrecht E, Renard Y, Desai N. Intravenous versus perineural dexamethasone to prolong analgesia after interscalene brachial plexus block: a systematic review with meta-analysis and trial sequential analysis. *Br J Anaesth*. 2024;133(1):135–145. doi:10.1016/j.bja.2024.03.042
36. Coviello A, Iacovazzo C, Cirillo D, et al. Dexamethasone versus dexmedetomidine as adjuvants in ultrasound popliteal sciatic nerve block for hallux valgus surgery: a mono-centric retrospective comparative study. *Drug Des Devel Ther*. 2024;18:1231–1245. doi:10.2147/DDDT.S442808