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Erector Spinae Plane Block With Liposomal Bupivacaine: Analgesic Adjunct in Adult Pectus Surgery

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ABSTRACT

Introduction: Pain management may be challenging in patients undergoing pectus excavatum (PE) bar removal surgery. To enhance recovery, opioid sparing strategies with regional anesthesia including ultrasound-guided erector spinae plane block (ESPB) have been implemented. The purpose of this study was to evaluate the safety and efficacy of bilateral ESPB with a liposomal bupivacaine/traditional bupivacaine mixture as part of an enhanced patient recovery pathway.

Materials and methods: A retrospective review of adult patients who underwent PE bar removal from January 2019 to December 2020 was performed. Perioperative data were reviewed and recorded. Patients who received ESPB were compared to historical controls (non-ESPB patients).

Results: A total of 202 patients were included (non-ESPB: 124 patients; ESPB: 78 patients). No adverse events were attributed to ESPB. Non-ESPB patients received more intraoperative opioids (milligram morphine equivalents; 41.8 ± 17.0 mg *versus* 36.7 ± 17.1, $P = 0.05$) and were more likely to present to the emergency department within 7 d postoperatively (4.8% *versus* 0%, $P = 0.05$) when compared to ESPB patients. No significant difference in total perioperative milligram morphine equivalents, severe pain in postanesthesia care unit (PACU), time from PACU arrival to analgesic administration, PACU length of stay, or postprocedure admission rates between groups were observed.

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Conclusions: In patients undergoing PE bar removal surgery, bilateral ESPB with liposomal bupivacaine was performed without complications. ESPB with liposomal bupivacaine may be considered as an analgesic adjunct to enhance recovery in patients undergoing cardiothoracic procedures but further prospective randomized clinical trials comparing liposomal bupivacaine to traditional local anesthetics with and without indwelling nerve catheters are necessary.

Introduction

Pectus excavatum (PE) is a congenital chest wall deformity that results in depression of the sternum and costal cartilage.[1] Symptoms, often secondary to reduced chest wall flexibility and cardiopulmonary compression, may progress with age but have been shown to improve or resolve following surgical repair.[2-5] Minimally invasive repair, or the modified Nuss procedure with 2-3 support bars, has become the standard of care in pediatric and adult patients due to excellent outcomes and enhanced patient recovery.[4] Approximately 3-5 y following support bar insertion, patients return for bar removal. Postoperative pain management may be challenging in patients undergoing bar removal surgery secondary to bilateral muscle incisions, intercostal nerve damage, and ossification near the bar insertion sites.[6,7] In an effort to enhance patient recovery, advances in perioperative care including multimodal, opioid sparing strategies with the use of regional anesthesia have been implemented into patient care pathways.[8,9]

Ultrasound-guided erector spinae plane block (ESPB) is a regional anesthesia technique that has gained popularity in thoracic and cardiac surgery, among others.[10-13] Local anesthetics is deposited in the erector spinae interfascial plane beneath the erector spinae muscle group and adjacent to the vertebral transverse process, providing anesthesia to a large portion of the thoracic cavity.[14] Compared to regional techniques performed proximal to the spinal cord and pleura (thoracic epidural and paravertebral block), the ESPB is performed more lateral and superficial, decreasing the risk of neuraxial injury and pneumothorax.[11] Furthermore, regional techniques performed lateral to the ESPB such as the pectoralis nerve block and serratus anterior nerve block do not consistently provide analgesia to the sternum, lateral, and posterior thorax.[13] This improved safety profile, in addition to successful opioid reduction, improved analgesia, decreased postoperative nausea and vomiting (PONV), and enhanced quality of recovery, has been described in patients undergoing thoracic and cardiac surgery.[10,13,15] The purpose of this study was to evaluate the safety and efficacy of ESPB with a mixture of liposomal bupivacaine (Exparel; Pacira BioSciences Inc, Parsippany, NJ) and traditional bupivacaine in patients undergoing pectus bar removal surgery.

Materials and Methods

Study sample

This study was approved by the Mayo Clinic Institutional Review Board. A written informed consent was waived for all patients who had previously granted permission to use their health records for observational research (consistent with Minnesota Statute 144.295). The study cohort was obtained from the institutional surgical database and all adult patients (aged $>$ 18 y) who underwent isolated PE bar removal surgery with the same surgical technique from January 1, 2019 to December 1, 2020 were included. Patients who had pectus procedures performed outside our institution, surgical procedures that occurred outside the study period, and patients who underwent additional simultaneous procedures were excluded. Patients who met inclusion criteria were further characterized as per whether ESPB was performed (ESPB group) or not (non-ESPB) during the study period.

Data collection/definitions

Medical records were comprehensively reviewed. Data collected included demographic and procedural data, medication administration including milligram morphine equivalents (MME), regional anesthetic description and anatomic location, local anesthetic administration, time to analgesic request upon postanesthesia care unit (PACU) arrival, postoperative pain scores at rest (using the visual analog scale [VAS]), PACU length of stay, and hospital length of stay. Records were evaluated for undesired patient outcomes including severe postoperative pain (VAS pain score $\geq$ 7), local anesthetic systemic toxicity, bradycardia requiring treatment (sustained heart rate $<$ 60 bpm treated with anticholinergic medication), evidence of sympathectomy, pleural puncture, PONV (defined as any antiemetic administered in the PACU), block site infection, hospital readmission, postoperative emergency room evaluation, and 30-d all-cause mortality. Preoperative, intraoperative, and postoperative opioids used for pain control were summed and converted to intravenous (IV) morphine equivalents based on the opioid used and their specific conversion factor. IV morphine equivalents were then converted to oral morphine equivalents/MME and used for statistical analysis.[16]

Perioperative management

Patients in the study had perioperative anesthetic and surgical care standardized per institutional protocol. At the time of prior Nuss bar insertion, elastomeric continuous infusion subcutaneous catheters with traditional local anesthetics were used for postoperative pain control in both patient cohorts. The use of cryoablation for Nuss bar insertion was not implemented until 2019 and no patients with prior cryoablation presented for bar removal during the study timeframe. All patients presenting for PE bar removal surgery underwent

general anesthesia with volatile anesthetic and/or propofol-based total IV anesthesia. Standard American Society of Anesthesiologist monitors in addition to an arterial line and transesophageal echocardiogram were used for intraoperative monitoring. Prior to 2020, ESPB were performed on a limited basis for PE bar removal procedures at our institution. Perioperative care was further standardized across the preoperative, intraoperative, and postoperative phase on January 5, 2020 with patients routinely being consented for preoperative ESPB (Fig. 1). To limit practice variability, providers were encouraged to administer intraoperative IV analgesics in a stepwise fashion (regardless of whether ESPB was performed) with fentanyl (maximum dose 200 mcg) being the first-line agent, followed by hydromorphone and/or ketamine as second-line agents if deemed necessary by the anesthesiologist. Surgical technique was consistent across the entire cohort with all bar removal procedures performed by a single surgeon. Regional anesthetics were completed in the preoperative area by a selected group of cardiac anesthesiologists trained and proficient in performing ESPB. Analgesic management in the PACU was consistent across the study cohort with first-line and second-line agents administered based on VAS pain scores as outlined in Figure 2.

Ultrasound-guided erector spinae plane block

Ultrasound-guided ESPB was performed in the preoperative area immediately prior to the procedure to maximize operating room efficiency. The patient was placed in the seated position on the edge of the bed with their upper extremities resting on a support stand and feet resting on the ground or a chair. The appropriate block level (typically T4-5 or T5-6) was identified and the patient was prepped and draped in sterile fashion. High-frequency (6-15 MHz) or low-frequency (2-5 MHz) ultrasound probes (SonoSite Edge II, X-Porte or PX; Fujifilm, Bothwell, WA) were used based on patient

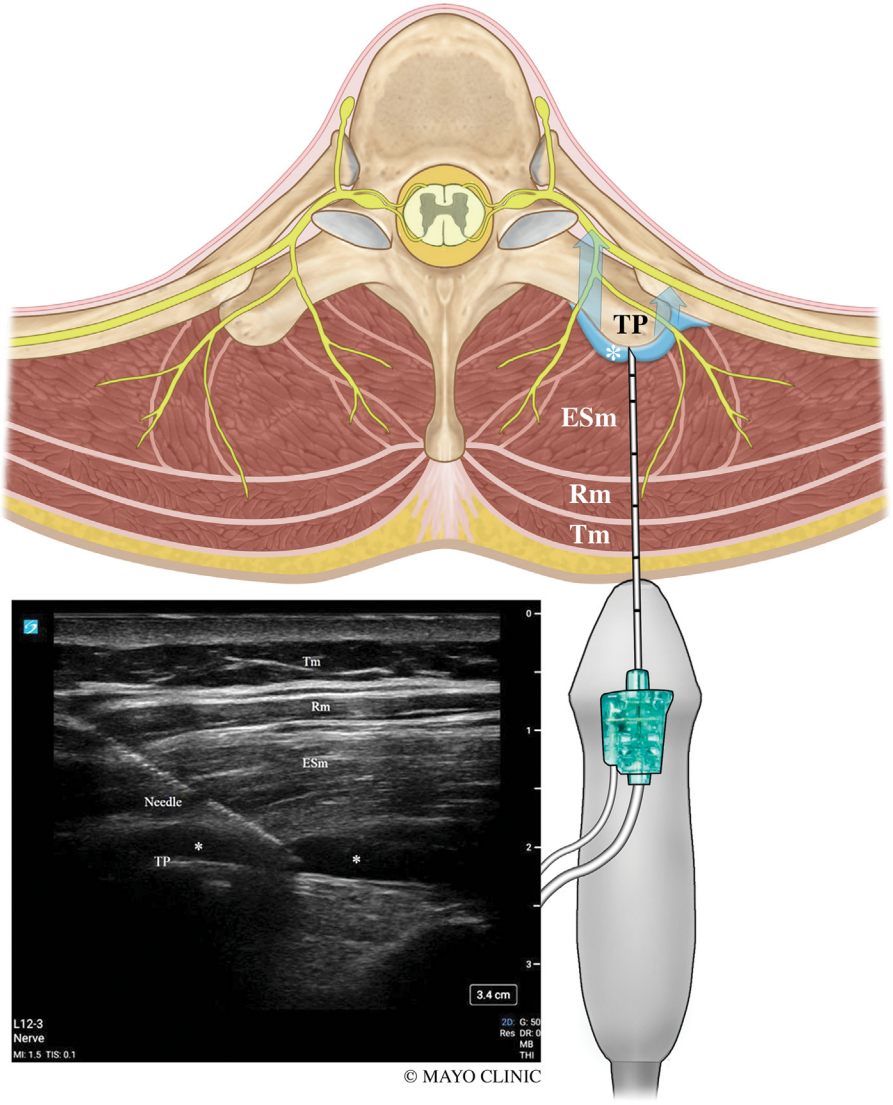

Fig. 1 – Illustration displaying ultrasound-guided erector spinae plane block with injection of local anesthetic. Abbreviations: ESm, erector spinae muscles; Rm, rhomboid muscle; Tm, trapezius muscle; TP, transverse vertebral process; *, local anesthetic deposition.

characteristics. With the probe in the sagittal plane and parallel to the spine, the proceduralist identified the spinous processes' and lamina medially and the ribs laterally. The transverse process was then identified with associated erector spinae musculature superficially. Either a 22G × 50 mm or 22G × 100 mm Stimuplex Ultra 360 Insulated Echogenic (Braun Medical Inc, Bethlehem, PA) or SonoPlex II Facet S (Pajunk, Geisingen, Germany) needle was inserted via an in-plane approach and advanced to the appropriate transverse process. Following negative aspiration, local anesthetic was injected in 5 mL increments ensuring adequate linear spread of local anesthetic 1-2 vertebral segments cephalad and caudad within the erector spinae interfacial plane (Fig. 1).

Surgeon wound infiltration

During the surgical procedure, all patients received surgeon wound infiltration of local anesthetic both into the intercostal spaces containing bars and subcutaneous tissues of the wound. Prior to the implementation of ESPB into clinical practice, 20-30 mL of 0.25% bupivacaine was mixed with 20 mL of liposomal bupivacaine and injected under direct visualization into bilateral surgical wound sites. Local anesthetic was administered in equivalent doses throughout the entire study cohort, as outlined in Figure 2.

Statistical analysis

The data were abstracted and entered in an Excel spreadsheet (Microsoft Corp, Redmond, WA). Patients who received preoperative, bilateral ESPB were compared to historical controls (non-ESPB). Demographic and perioperative data were descriptively summarized using mean ± standard deviation for continuous variables and frequency percentages for categorical variables. Patient and procedural characteristics were compared using Mann–Whitney *U*-test for continuous variables and chi-squared testing (or Fisher's exact test) for categorical variables. A Shapiro–Wilk test was used to assess the normality of the residuals. Two-tailed tests were used with statistical significance inferred with a P value ≤ 0.05. The available sample size had 80% power (alpha = 0.05) to detect a difference in MME of 7 mg or more (representing an effect size of 0.40) in total intraoperative MME between non-ESPB and ESPB groups. A recent meta-analysis reported that ESPB significantly reduced 24-h opioid consumption by −10.5 mg compared with nonblock groups.[10] A cost analysis was performed for a period of 30 d from the index encounter. Cost datum was retrieved from the cost data warehouse, an institutional resource that converts internal costs to standardized costs for publication.[17] A standardized cost was created by applying Medicare reimbursement rates to professional services and using hospital cost-to-charge ratios for all hospital-based services. These standardized costs can then be used for publication and comparison. All costs were inflated to 2020 US dollars. A generalized linear model was used for the cost comparison between the two groups. All statistical analysis was completed in SAS Version 9.4 (SAS Institute Inc Cary, NC).

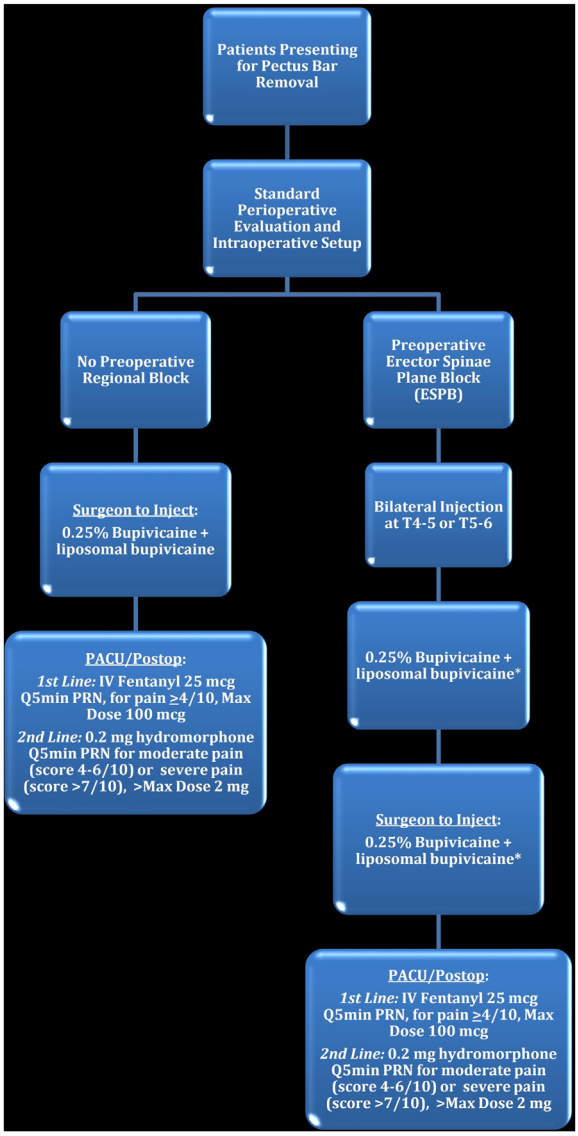

Fig. 2 – Flow diagram outlining pectus bar removal local anesthetic administration.

Results

A total of 202 patients underwent PE bar removal surgery during the study period and met inclusion for analysis; 78 patients received bilateral ESPB and 124 patients received surgeon wound infiltration alone. Patient demographics and surgical characteristics are displayed in Table 1. Ultrasound-guided ESPB was performed at the T4-5 or T5-6 vertebral level in 46 patients (59%). There were 23 patients (30%) where anatomic block location was not listed in the procedure note in the electronic medical record. Local anesthetic most frequently administered consisted of liposomal bupivacaine + 0.25% bupivacaine in 64 patients (82%) or liposomal bupivacaine + 0.5% bupivacaine in 10 patients (13%). There were no cases of local anesthetic systemic toxicity, pleural

Table 1 – Patient demographics and surgical data.

Characteristic	No ESPB ($n = 124$)	ESPB ($n = 78$)	Total ($n = 202$)	P value
Gender, *n* (%)				0.48*
Female	28 (22.6%)	21 (26.9%)	49 (24.3%)	
Male	96 (77.4%)	57 (73.1%)	153 (75.7%)	
Age				0.78†
N	124	78	202	
Mean (SD)	35.1 (11.03)	35.0 (12.03)	35.1 (11.39)	
Median (IQR)	33.0 (27.0, 43.0)	31.5 (25.0, 44.0)	32.5 (26.0, 43.0)	
Range	18.0, 59.0	18.0, 67.0	18.0, 67.0	
BMI (kg/m^2)				0.34†
N	124	76	200	
Mean (SD)	23.0 (3.59)	22.5 (4.05)	22.8 (3.77)	
Median (IQR)	22.4 (20.7, 25.4)	22.8 (19.0, 25.0)	22.5 (20.0, 25.2)	
Range	16.0, 32.2	15.2, 31.6	15.2, 32.2	
Haller index				0.24†
N	120	75	195	
Mean (SD)	5.1 (2.95)	5.2 (2.99)	5.2 (2.96)	
Median (IQR)	4.5 (3.8, 5.5)	4.2 (3.6, 4.9)	4.4 (3.7, 5.3)	
Range	1.8, 25.0	2.6, 18.0	1.8, 25.0	
Number of support bars				0.02†
N	124	78	202	
Median (IQR)	2.0 (2.0, 3.0)	2.0 (2.0, 2.0)	2.0 (2.0, 3.0)	
Range	1.0, 3.0	1.0, 3.0	1.0, 3.0	
Time from bar insertion to removal (d)				0.89†
N	124	77	201	
Mean (SD)	1288.0 (426.39)	1315.8 (481.96)	1298.7 (447.51)	
Median (IQR)	1156.0 (1097.0, 1291.0)	1166.0 (1097.0, 1304.0)	1157.0 (1097.0, 1302.0)	
Range	263.0, 4130.0	172.0, 3342.0	172.0, 4130.0	
Surgery duration (min)				0.41†
N	124	78	201	
Mean (SD)	51.8 (21.3)	54.3 (19.9)	52.8 (20.7)	
Median (IQR)	45.0 (38.0, 58.5)	50.5 (40.0, 61.0)	47.0 (39.0, 59.0)	
Range	26.0, 126.0	28.0, 132.0	26.0, 132.0	

BMI = body mass index; ESPB = erector spinae plane block; IQR = interquartile range; *n*/*N* = number; SD = standard deviation.
* Chi-square *P* value.
† Wilcoxon rank sum *P* value.

puncture, block site infection, or sympathectomy attributed to ESPB. Intraoperative bradycardia requiring treatment occurred in seven non-ESPB patients (5.6%) and in eight ESBP patients (10.3%; $P = 0.2236$). Preoperative and intraoperative analgesic medication administration data are displayed in Table 2. Intraoperative hydromorphone MME (7.5 ± 11.33 mg *versus* 3.7 ± 8.54 mg, $P = 0.003$) and total intraoperative MME (41.8 ± 17.0 mg *versus* 36.7 ± 17.1, $P = 0.05$) were significantly higher in the non-ESPB group *versus* the ESPB group, respectively. The effect size observed in this study was 0.30.

PACU outcomes are reported in Table 3. The maximum postoperative VAS pain score at 0-2 h was significantly lower in the non-ESPB *versus* ESPB group (3.0 ± 2.90 *versus* 4.1 ± 2.89, $P = 0.01$), but not likely clinically significant. Postoperative characteristics, outcomes, and cost analysis are reported in Table 4. Outpatient clinic follow-up within 7 d of PACU or hospital discharge occurred with 122 (98%) non-ESPB patients and 78 (100%) ESPB patients. Nine patients in the non-ESPB group were admitted following surgery: four patients had poorly controlled postoperative pain, four patients were observed overnight due to intraoperative bleeding or surgical difficulty, and one patient did not have a caretaker available upon hospital discharge. Five patients in the ESPB group were admitted following surgery: two patients were observed overnight due to surgical difficulty, one patient was admitted with poorly controlled postoperative pain, one patient had postoperative bilateral pneumothorax requiring chest tube insertion, and one patient who was previously lost to follow-up was observed overnight due to bar removal beyond the recommended time frame. One patient in the non-ESPB group was readmitted within 7 d of surgery for surgical wound infection. Six patients in the non-ESPB group were evaluated

Table 2 – Preoperative and intraoperative analgesic medications.

Characteristic	Regional block		Total ($n = 202$)	P value
	No ESPB ($n = 124$)	ESPB ($n = 78$)		
Preoperative fentanyl, *n* (%)				< 0.001*
0 mcg	124 (100%)	61 (78.2%)	61 (78.2%)	
25 mcg	0 (%)	2 (2.6%)	2 (2.6%)	
50 mcg	0 (%)	5 (6.4%)	5 (6.4%)	
100 mcg	0 (%)	10 (12.8%)	10 (12.8%)	
Preoperative oral acetaminophen, *n* (%)				0.31*
No	107 (86.3%)	71 (91.0%)	178 (88.1%)	
Yes	17 (13.7%)	7 (9.0%)	24 (11.9%)	
Preoperative gabapentin, *n* (%)				0.19*
No	107 (86.3%)	72 (92.3%)	179 (88.6%)	
Yes	17 (13.7%)	6 (7.7%)	23 (11.4%)	
Intraoperative IV acetaminophen				0.08*
No	24 (19.4%)	8 (10.3%)	32 (15.8%)	
Yes	100 (80.6%)	70 (89.7%)	170 (84.2%)	
Intraoperative ketamine (mg)				1.00†
N	124	78	202	
Mean (SD)	12.6 (17.15)	12.7 (17.26)	12.6 (17.15)	
Median (IQR)	0.0 (0.0, 30.0)	0.0 (0.0, 30.0)	0.0 (0.0, 30.0)	
Range	0.0, 50.0	0.0, 50.0	0.0, 50.0	
Intraoperative ketorolac (mg)				0.46†
N	124	78	202	
Mean (SD)	22.0 (12.61)	23.3 (12.00)	22.5 (12.36)	
Median (IQR)	30.0 (15.0, 30.0)	30.0 (15.0, 30.0)	30.0 (15.0, 30.0)	
Range	0.0, 30.0	0.0, 30.0	0.0, 30.0	
Intraoperative fentanyl, *n* (%)				0.71*
No	5 (4.0%)	4 (5.1%)	9 (4.5%)	
Yes	119 (96.0%)	74 (94.9%)	193 (95.5%)	
Intraoperative fentanyl MME				0.91†
N	124	78	202	
Mean (SD)	32.3 (13.40)	33.0 (16.46)	32.6 (14.62)	
Median (IQR)	25.0 (25.0, 50.0)	25.0 (25.0, 50.0)	25.0 (25.0, 50.0)	
Range	0.0, 75.0	0.0, 75.0	0.0, 75.0	
Intraoperative hydromorphone MME				0.003†
N	124	78	202	
Mean (SD)	7.5 (11.33)	3.7 (8.54)	6.1 (10.49)	
Median (IQR)	0.0 (0.0, 12.0)	0.0 (0.0, 0.0)	0.0 (0.0, 10.0)	
Range	0.0, 40.0	0.0, 40.0	0.0, 40.0	
Total intraoperative MME				0.05†
N	124	78	202	
Mean (SD)	41.8 (17.01)	36.7 (17.12)	39.8 (17.19)	
Median (IQR)	37.5 (33.0, 50.0)	35.0 (25.0, 50.0)	37.5 (25.0, 50.0)	
Range	0.0, 145.0	0.0, 85.0	0.0, 145.0	

ESBP = erector spinae plane block; IV = intravenous; IQR = interquartile range; LOS = length of stay; *n*/*N* = number; mcg = micrograms; mg = milligrams; MME = milligram morphine equivalents; SD = standard deviation.

* Chi-square *P* value.

† Wilcoxon rank sum *P* value.

Table 3 – PACU outcomes.

Characteristic	No ESPB ($n = 124$)	ESPB ($n = 78$)	Total ($n = 202$)	P value
Total PACU MME				0.59*
N	124	78	202	
Mean (SD)	8.8 (16.33)	8.5 (14.69)	8.7 (15.68)	
Median (IQR)	0.0 (0.0, 12.5)	0.0 (0.0, 12.5)	0.0 (0.0, 12.5)	
Range	0.0, 86.0	0.0, 65.0	0.0, 86.0	
Total perioperative MME‡				0.06†
N	124	78	202	
Mean (SD)	50.6 (23.23)	55.5 (24.52)	52.5 (23.80)	
Median (IQR)	49.5 (37.0, 60.5)	50.0 (43.8, 63.3)	50.0 (37.5, 62.5)	
Range	0.0, 152.5	0.0, 122.5	0.0, 152.5	
Time from PACU arrival to analgesic administration (min)				0.61*
N	57	44	101	
Mean (SD)	36.2 (35.65)	33.6 (25.13)	35.1 (31.39)	
Median (IQR)	22.0 (15.0, 41.0)	26.0 (17.5, 41.5)	24.0 (16.0, 41.0)	
Range	1.0, 189.0	7.0, 130.0	1.0, 189.0	
Severe pain in PACU§, *n* (%)				0.06†
No	104 (83.9%)	57 (73.1%)	161 (79.7%)	
Yes	20 (16.1%)	21 (26.9%)	41 (20.3%)	
Maximum postoperative VAS pain scores at 0-2 h				0.01*
N	124	78	202	
Mean (SD)	3.0 (2.90)	4.1 (2.89)	3.5 (2.94)	
Median (IQR)	3.0 (0.0, 5.0)	4.5 (2.0, 6.0)	3.5 (0.0, 6.0)	
Range	0.0, 10.0	0.0, 10.0	0.0, 10.0	
Maximum postoperative VAS pain scores at 2-6 h				0.13*
N	36	22	58	
Mean (SD)	2.5 (2.34)	3.1 (1.96)	2.7 (2.21)	
Median (IQR)	2.0 (0.0, 4.0)	3.5 (3.0, 4.0)	3.0 (0.0, 4.0)	
Range	0.0, 8.0	0.0, 6.0	0.0, 8.0	
PONV reported in PACU, *n* (%)				0.79†
No	88 (71.0%)	54 (69.2%)	142 (70.3%)	
Yes	36 (29.0%)	24 (30.8%)	60 (29.7%)	
PACU LOS (min)				0.23*
N	124	78	202	
Mean (SD)	105.4 (74.55)	107.2 (64.74)	106.1 (70.76)	
Median (IQR)	82.0 (56.5, 135.0)	97.0 (64.0, 126.0)	85.0 (61.0, 129.0)	
Range	30.0, 432.0	30.0, 472.0	30.0, 472.0	

ESBP = erector spinae plane block; IQR = interquartile range; LOS = length of stay; *n*/*N* = number; min = minutes; MME = milligram morphine equivalents; PACU = postanesthesia care unit; PONV = postoperative nausea and vomiting; SD = standard deviation; VAS = visual analog scale.
* Wilcoxon rank sum *P* value.
† Chi-square *P* value.
‡ Total preoperative, intraoperative, and PACU OME.
§ Any PACU pain score ≥ 7/10.

in the emergency department within 7 d of surgery (Table 3): two patients had uncontrolled postoperative pain, one patient developed refractory PONV secondary to oral opioid use, one patient had PONV without postoperative opioid use, one patient had surgical site bleeding, and one patient had concern for infection. Demographic and perioperative data from these six patients revealed a Haller Index of 3.6 + 0.32 (median 3.7, range 3.0-3.8), number of support bars of 2.3 + 0.52 (median 2, range 2-3), time from bar insertion to removal of 1179.2 + 69.4 d (median 1167.0, range 1114.0-1298.0), surgical duration of 54.5 + 17.8 min (median 47.5, range 34.0-78.0), and total perioperative MME of 46.2 + 18.2 mg (median 40.6, range 25.0-76.3). There were no cases of 30-d mortality.

Discussion

Previous studies evaluating ESPB have demonstrated the analgesic efficacy of this technique in patients undergoing cardiac and thoracic surgery.[12,13,18] Herein we present a study

Table 4 – Postoperative outcomes.

Characteristic	No ESPB ($n = 124$)	ESPB ($n = 78$)	Total ($n = 202$)	P value
Patient admitted to inpatient, *n* (%)				0.82[†]
No	115 (92.7%)	73 (93.6%)	188 (93.1%)	
Yes	9 (7.3%)	5 (6.4%)	14 (6.9%)	
Outpatient clinic VAS pain score				0.31[*]
N	87	65	152	
Mean (SD)	2.9 (1.95)	3.2 (1.78)	3.0 (1.88)	
Median (IQR)	3.0 (2.0, 4.0)	3.0 (2.0, 4.0)	3.0 (2.0, 4.0)	
Range	0.0, 10.0	0.0, 8.0	0.0, 10.0	
Emergency department visit within 7 d postoperative, *n* (%)				0.05[†]
No	118 (95.2%)	78 (100.0%)	196 (97.0%)	
Yes	6 (4.8%)	0 (0.0%)	6 (3.0%)	
Hospital readmission within 7 d postoperative, *n* (%)				0.43[†]
No	123 (99.2%)	78 (100.0%)	201 (99.5%)	
Yes	1 (0.8%)	0 (0.0%)	1 (0.5%)	
Cost analysis (USD)				
N	118	77	195	
Index cost				< 0.001[*]
Mean (SD)	8980.56 (1481.20)	9960.74 (1678.83)	9367.61 (1630.35)	
Median (IQR)	8762.39 (7908.8-9813.1)	9700.60 (8691.7-10,871.4)	9045.26 (8275.0-10,420.8)	
Range	6382.43-13,298.49	6891.79-16,035.14	6382.43-16,035.14	
7-d cost				< 0.001[*]
Mean (SD)	9082.66 (1601.24)	10,113.67 (2355.82)	9489.78 (1993.94)	
Median (IQR)	8765.16 (7995.2-9876.8)	9700.60 (8826.8-10,902.3)	9179.32 (8296.4-10,454)	
Range	6382.43-14,571.86	6925.00-25,783.06	6382.43-25,783.06	
30-d cost				< 0.01[*]
Mean (SD)	9214.11 (1985.27)	10,115.27 (2356.65)	9569.95 (2178.93)	
Median (IQR)	8770.61 (7995.2-9945.5)	9700.60 (8826.8-10,902.3)	9206.76 (8296.4-10,581.9)	
Range	6382.43-20,815.82	6925.00-25,783.06	6382.43-25,783.06	

ESBP = erector spinae plane block; IQR = interquartile range; *n*/*N* = number; SD = standard deviation; USD = US dollars; VAS = visual analog scale.
[*] Wilcoxon rank sum *P* value.
[†] Chi-square *P* value.

where ESPB containing liposomal bupivacaine was incorporated into a perioperative enhanced recovery pathway as an analgesic adjunct in patients undergoing PE bar removal surgery. The main findings of this study are patients who received bilateral ESPB with liposomal bupivacaine mixed with regular bupivacaine tolerated the procedure well without adverse events. Furthermore, ESPB patients had significantly lower intraoperative MME requirements and were less likely to present to the emergency department within 7 d postoperatively compared to patients who did not receive ESPB. There were no significant differences in total perioperative MME, rate of severe pain in the PACU, time from PACU arrival to analgesic administration, PACU length of stay, or postprocedure admission rates between groups.

Bilateral ESBP were introduced into our perioperative PE bar removal pathway to ideally provide more extensive local anesthetic coverage of the lateral and anterior thorax and reduce perioperative systemic opioid requirements than what was previously achieved with surgeon wound infiltration alone. Preoperative ESPBs were easily adopted and implemented into our perioperative pectus bar removal surgery protocols. At the onset of this study, no published data were available on the use of ESPB with liposomal bupivacaine for cardiothoracic surgery. The addition of liposomal bupivacaine to ESPB is of interest to clinicians due to the potential for prolonged analgesia compared to traditional bupivacaine or ropivacaine.[19] As an alternative, continuous infusion catheters inserted into the erector spinae plane with traditional local anesthetic infusions have been reported previously.[18] The concern for infection, bleeding, dislodgement, and need for postoperative management made the use of continuous local anesthetic infusion less desirable in our patient population as we strive to achieve same same-day surgery.

Only two prior studies have described ESPB with liposomal bupivacaine in patients undergoing cardiothoracic surgery. In a retrospective case-control study, Song *et al.*[20] reported eight

cases of bilateral ESPB with liposomal bupivacaine compared to 16 matched controls in patients undergoing cardiotomy at a single institution. Like the present study, the authors reported significantly reduced opioid consumption intraoperatively but also less opioid consumption at 4 and 12 h postextubation. There was no significant difference in opioid consumption > 12 h after extubation, no difference in postoperative VAS pain scores, breakthrough pain, duration of mechanical ventilation, intensive care unit length of stay, hospital length of stay, and no reported adverse events or local anesthetic systemic toxicity. Voulgarelis *et al.*[21] reported the use of ESPB with liposomal bupivacaine in three pediatric patients during congenital cardiac surgery. The authors report low pain and sedation scores in all patients with no opioid requirement following chest tube removal. There were no complications secondary to ESPB or cases of local anesthetic systemic toxicity.

In the present study, we report a significant reduction in intraoperative MME but no difference in total PACU MME or total perioperative MME between ESPB and non-ESBP patients, respectively (Tables 3 and 4). It is important to note that 17 patients (22%) in the ESPB group received preoperative fentanyl at the time of ESPB which may have impacted the total perioperative MME. Moreover, given the nonblinded nature of the study, administration of intraoperative opioids may have been influenced based on providers knowledge of preoperative ESPB. To limit practice variability related to IV opioid administration, anesthesia providers were encouraged to administer intraoperative opioids in a stepwise fashion to all patients, with fentanyl (maximum dose 200 mcg) being the first-line agent, followed by hydromorphone and/or ketamine as second-line agents if deemed necessary by the anesthesiologist. The significantly higher dose of intraoperative hydromorphone administered to non-ESPB patients (Table 2) may have been secondary to a perceived increased analgesic requirement in those patients. Furthermore, the higher dose of intraoperative long-acting opioid (hydromorphone) in the non-ESPB group may have influenced PACU opioid requirements in those patients.

Nonetheless, the reduction in MME in the present study is modest in contrast to previous studies comparing ESPB to intercostal nerve blocks.[12,22] This may be secondary to a conservative dosing strategy of liposomal bupivacaine/traditional bupivacaine in the present study due to the paucity of literature describing the administration of liposomal bupivacaine in ESPB. Furthermore, the need for bilateral injection, concern to not exceed the maximum allowable local anesthetic dose, and the potential for spread of local anesthetic into the paravertebral or epidural space observed in some cadaveric and radiographic studies[23] further underscored a conservative dosing strategy in the present study. While the total dose and volume of local anesthetic administered via the ESPB was less than reported in other studies,[12,20] we observed satisfactory local anesthetic spread to adjacent vertebral spaces both cephalad and caudad to the sight of injection under direct ultrasound guidance. As this is the largest study evaluating the ESPB with liposomal bupivacaine, it is important to note the lack of adverse events attributed to ESPB. Intraoperative bradycardia requiring treatment did occur in 10.3% of patients with ESPB *versus* 5.6% of patients without ESPB, although not statistically significant ($P = 0.22$). Importantly, no cases of local anesthetic systemic toxicity or sympathectomy were observed. However, clinicians should maintain vigilance to adequately assess the safety of liposomal bupivacaine with various dosing strategies, considering patient characteristics, surgical procedure type, and the potential for additional local anesthetic administration following administration of liposomal bupivacaine.

A pertinent finding of the present study is the significant difference in emergency department evaluation within 7 d postoperatively between ESPB and non-ESPB patients. These six patients had a similar number of support bars removed ($2.3 + 0.52$ *versus* $2.3 + 0.50$; $P = 1.0$), time from bar insertion to removal ($1179.2 + 69.4$ *versus* $1298.7 + 447.5$ d; $P = 0.52$), and surgical duration ($54.5 + 17.8$ *versus* $52.8 + 20.7$ min) compared to the entire study cohort, respectively. This may signal some analgesic benefit secondary to the extended release of liposomal bupivacaine that persists beyond the immediate postoperative period. Despite these potential benefits, recent studies have called into question the clinical effectiveness of liposomal bupivacaine administered by infiltration or brachial plexus peripheral nerve blocks compared to traditional local anesthetics.[24,25] As described previously, the addition of liposomal bupivacaine to ESPB may be advantageous due to the potential for prolonged analgesia compared to bupivacaine or ropivacaine alone but further study specifically evaluating its clinical efficacy in ESPB is required.[19] ESPB with liposomal bupivacaine offers the theoretical benefits of more complete and protracted analgesic coverage to the thorax but further prospective randomized clinical trials comparing liposomal bupivacaine in ESPB compared to traditional local anesthetics with and without indwelling nerve catheters are necessary.

Limitations

Limitations of this study include those inherent to a retrospective analysis including charting inaccuracies, omissions, and the potential for data misinterpretation. Furthermore, despite nearly all patients having outpatient follow-up within 7 d of PACU or hospital discharge, many patients present to our tertiary referral center specifically for perioperative care and receive extended follow-up care elsewhere; thus, extended postoperative data may have been incomplete. All patient medical records were individually reviewed for evidence of chronic pain and prolonged opioid use but standardized documentation of the dose, frequency, and duration of prescribed outpatient opioid use was not reported in the medical record. Moreover, since the study cohort largely consisted of ambulatory surgery patients, extended postoperative follow-up with comprehensive evaluation of postdischarge analgesic effectiveness was challenging. While authors used direct spread of local anesthetic cephalad and caudad under live ultrasound guidance as confirmation of successful ESBP, further objective assessment of anesthetic block was not performed and could not be proven. Given the nonblinded nature of the study, administration of perioperative opioids and the results herein may have been influenced based on providers knowledge of preoperative ESPB. Finally, the volume of medication administered in the ESPB to achieve

satisfactory spread of local anesthetic may have been plausible given the young age (35.0 + 12.0 y) and body habitus (body mass index 22.5 + 4.1 kg/m^2) of our patient population (Table 1); thus, various dosing strategies may be necessary in differentpatient cohorts. Despite the present study being one of the largest evaluating ESPB in cardiothoracic surgery patients, the relatively small sample size makes it challenging to identify clinically significant differences between groups with regard to the outcomes of interest. While a cost analysis was performed on this cohort, healthcare cost data are well known to be highly skewed, which is why a larger study, adjusting for potential confounders, is necessary. Specifically for our study, we are concerned that the data may be skewed by subtle variations in the cohort such as postoperative hospital admission and perioperative workflow changes secondary to the COVID-19 pandemic at the end of the study period. Further large, randomized, controlled trials designed with intermediate and long-term follow-up are necessary to evaluate ESPB with liposomal bupivacaine compared to traditional local anesthetics to determine the optimal volume of local anesthetic and establish definitive safety data.

Conclusions

In patients undergoing PE bar removal surgery, bilateral ESPB with liposomal bupivacaine was performed without complication. ESPB with liposomal bupivacaine may be considered as an analgesic adjunct when added to perioperative enhanced recovery protocols in adult patients undergoing PE bar removal surgery but further prospective randomized clinical trials comparing liposomal bupivacaine to traditional local anesthetics with and without indwelling nerve catheters are necessary.

Author Contributions

S.H.M.: This author helped with study design, data analysis, manuscript preparation, revision, and final approval.

D.E.J.: This author helped with study design, data analysis, manuscript preparation, revision, and final approval.

R.C.C.: This author helped with study design, data analysis, manuscript preparation, revision, and final approval.

R.A.W.: This author helped with study design, data analysis, manuscript preparation, revision, and final approval.

A.W.M.: This author helped with study design, data analysis, manuscript preparation, revision, and final approval.

J.R.M.: This author helped with data analysis, manuscript preparation, revision, and final approval.

M.E.G.: This author helped with study design, data analysis, manuscript preparation, revision, and final approval.

A.S.A.: This author helped with data analysis, manuscript preparation, revision, and final approval.

R.D.: This author helped with data analysis, revision, and final approval.

B.J.B.: This author helped with data analysis, revision, and final approval.

B.B.S.: This author helped with study design, data analysis, manuscript preparation, revision, and final approval.

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