JCS Journal of Chest Surgery
https://doi.org/10.5090/jcs.23.139
pISSN: 2765-1606 eISSN: 2765-1614
J Chest Surg. 2024;57(3):291-299

Clinical Research

Serratus Anterior Plane Block: A Better Modality of Pain Control after Pectus Excavatum Repair

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ARTICLE INFO
Received October 6, 2023
Revised January 3, 2024
Accepted January 15, 2024

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See Commentary page 300.

Background: Postoperative pain management following minimally invasive repair of pectus excavatum (MIRPE) remains a critical concern due to severe post-procedural pain. Promising results have been reported for cryoanalgesia following MIRPE; however, its invasiveness, single-lung ventilation, and additional instrumentation requirements remain obstacles. Serratus anterior plane block (SAPB) is a regional block technique capable of covering the anterior chest wall at the T2–9 levels, which are affected by MIRPE. We hypothesized that SAPB would be a superior alternative pain control modality that reduces postoperative pain more effectively than conventional methods.
Methods: We conducted a retrospective study of patients who underwent MIRPE between March 2022 and August 2023. The efficacy of pain control was compared between group N (conventional pain management, n=24) and group S (SAPB, n=26). Group N received intravenous patient-controlled analgesia (IV-PCA) and subcutaneous local anesthetic infusion. Group S received bilateral continuous SAPB with 0.3% ropivacaine after a bilateral bolus injection of 30 mL of 0.25% ropivacaine with baseline IV-PCA. Pain levels were evaluated using a Visual Analog Scale (VAS) at 1, 3, 6, 12, 24, 48, and 72 hours postoperatively and total intravenous rescue analgesic consumption by morphine milligram equivalents (MME).
Results: Mean VAS scores were significantly lower in group S than in group N throughout the 72-hour postoperative period ($p<0.01$). Group S showed significantly lower MME at postoperative 72 hours (group N: 108.53, group S: 16.61; $p<0.01$).
Conclusion: SAPB improved immediate postoperative pain control in both the resting and dynamic states and reduced opioid consumption compared to conventional management.

Keywords: Pectus excavatum, Serratus anterior plane block, Postoperative pain, Cryoanlgesia, Minimally invasive repair of pectus excavatum

Introduction

Pectus excavatum (PE), which is characterized by anterior chest wall depression and costal deformation, is the most common congenital chest wall deformity. Advances in surgical techniques and the introduction of innovative surgical instruments have significantly improved the correction of these deformities [1,2]. However, managing severe postoperative pain following PE repair remains a significant challenge, as current solutions are inadequate. The remodeling of the chest wall with pectus bars exerts considerable pressure on the rib cage, leading to intense postoperative pain [3,4]. Traditional pain management strategies for PE repair, such as intravenous (IV) patient-controlled analgesia (PCA), thoracic epidural analgesia, and local wound infiltration using the ON-Q PainBuster (B Braun, Hessen, Germany), are not fully effective in controlling pain [5-8].

Recent studies have shown that cryoanalgesia enhances postoperative pain management after PE repair compared

https://doi.org/10.5090/jcs.23.139

to traditional methods [9-11]. However, the application of cryoanalgesia necessitates a thoracoscopic approach, single-lung ventilation, and additional instrumentation, factors that restrict its widespread adoption following PE repair [11].

As a superior alternative, we adopted the continuous serratus anterior plane block (SAPB), which is a technique that administers local anesthetic via an extrathoracic catheter. This method targets the thoracic dermatomes from T2 to T9 by blocking the lateral cutaneous branches of the intercostal nerves that traverse these planes [12]. In this study, we aimed to assess the effectiveness of SAPB in managing postoperative pain following PE repair, in comparison to conventional pain management techniques.

Methods

Study design

This retrospective study was reviewed and approved by the institutional review board of Seoul St. Mary's Hospital (IRB no., KC23RISI0889). We analyzed data from patients who underwent minimally invasive repair of pectus excavatum (MIRPE) between March 1, 2022 and August 30, 2023. Out of the 126 patients who underwent MIRPE, 50 met the criteria for inclusion in the study. We only considered cases of primary repair and excluded patients if they lacked complete medical records pertaining to pain and analgesic data, had a history of pectus surgery, or had undergone sternotomy. The patients were categorized into 2 cohorts based on the pain control methods used: 24 patients received conventional pain management (group N), and 26 patients were treated with SAPB (group S) (Fig. 1). The integration of SAPB into our pain control protocol marked a change in our clinical practice beginning in 2023. The selection of patients for this study included the most recent cases using conventional methods as well as those involving SAPB, with the aim of minimizing potential enrollment biases by ensuring that the time frames for both groups were closely aligned.

Demographic data, medications administered, surgical and medical histories, and perioperative data—including operative time, pain level, opioid use, complications, and length of stay (LOS)—were collected through patient interviews and electronic medical records. The total IV rescue analgesic consumption was quantified using the approximate morphine milligram equivalent (MME).

The degree of postoperative pain was assessed using a Visual Analog Scale (VAS) at multiple time points (1, 3, 6, 12, 24, 48, and 72 hours) following surgery. Patients reported their pain intensity on a scale ranging from 0 (no pain) to 10 (worst imaginable pain) in both the supine position (at rest, VAS-R) and while in an upright position during coughing (dynamic, VAS-D). A VAS score <4 was deemed to represent a tolerable level of pain.

The total consumption of IV rescue analgesics at postoperative intervals (6, 12, 24, 48, and 72 hours), LOS, and complications—including those related to SAPB, such as pneumothorax, wound complications, pneumonia, neurological issues, bar dislocation, or re-operation—were recorded and compared between the 2 groups. Additionally, the total operative time and the duration of the SAPB were noted and analyzed.

The depression index was calculated by locating the

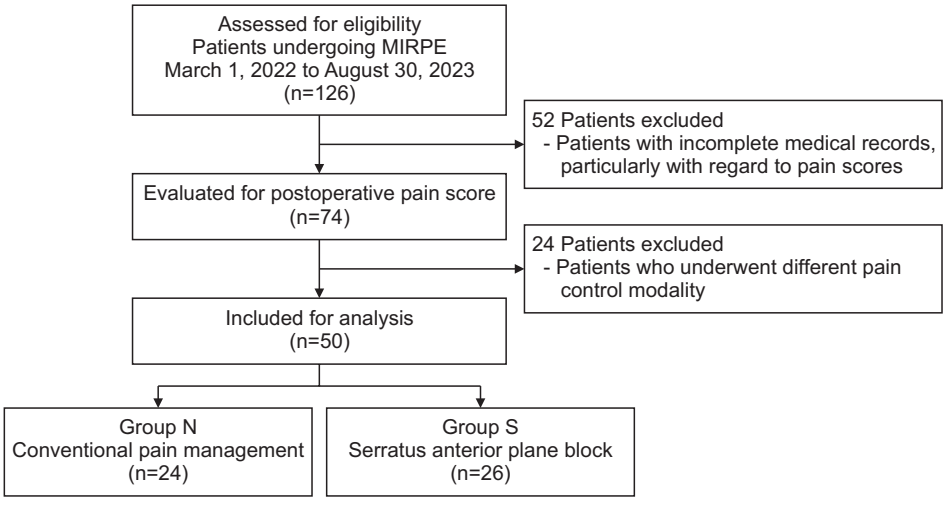

Fig. 1. CONSORT flow diagram for patient enrollment, allocation, and analysis. MIRPE, minimally invasive repair of pectus excavatum.

point of maximal sternal depression on computed tomography images and drawing a line across the anterior ribs at this point [13].

Surgical procedures

All PE repairs were performed by 1 surgeon at a single center. The surgical techniques were identical except for the SAPB procedure. Patients were positioned supine, with both arms freely suspended in overhead slings to avoid arm stretching. Bilateral chest wall incisions were made at the mid-axillary line, each approximately 1 cm in length, to accommodate the insertion of a pectus bar [11].

Our center's surgical strategy emphasizes remodeling the entire chest wall rather than merely elevating the focal depression [2]. Before repair, the total crane technique was applied to every patient, regardless of age, sex, or severity. This technique involves lifting the sternum above the desired height using a sternal wire or screw attached to the depressed area, and it was utilized in every case [14]. For visualization and dissection, we used a pectoscope (PrimeMed, Seoul, Korea), which allowed us to insert a pectus bar through the intercostal spaces at the anterior axillary lines on both sides. This approach was taken to ensure the highest quality of repair and to maintain the anatomical integrity of the reshaped chest wall. To stabilize the bars, multiple pectus bars were introduced and secured to bilateral bridge plates (PrimeMed). In 2022, we discontinued the use of single-bar repairs for chest wall remodeling in all patients. To address costal flares and remaining protrusions, we applied the flare-buster/magic string technique, which involves the use of No. 5 Ethibond strings (Ethicon Inc., Somerville, NJ, USA) [15,16].

Serratus anterior plane block

SAPB was performed twice: initially before the PE repair procedure as an initial bolus, and subsequently after the completion of the PE repair for continuous infusion during the postoperative period. For the procedure, the patient was positioned supine, and a high-frequency linear ultrasound transducer was positioned anterior to the midaxillary line at the level of the fourth or fifth ribs on the side to be blocked (Fig. 2A) [17,18]. The serratus anterior (SA) and latissimus dorsi (LD) muscles were identified, and a 20G BD Perisafe Modified Tuohy Point Epidural Needle (BD Inc., Eschborn, Germany) was advanced into the interfascial plane between the SA and LD using an ultrasound-guided in-plane technique. Initially, 5–10 mL of saline was injected to expand the interfascial space between the SA and LD. Then, 30 mL of 0.25% ropivacaine (not exceeding a maximum dose of 3 mg/kg of ropivacaine) was administered bilaterally, along with adjuvants of 5 mg of dexamethasone and 50 μg of fentanyl to enhance the quality and duration of the local anesthetic effect (Fig. 2B, C). This approach blocks the lateral cutaneous branches of the second to ninth intercostal nerves and the long thoracic nerve, providing anesthesia to the anterior and lateral as-

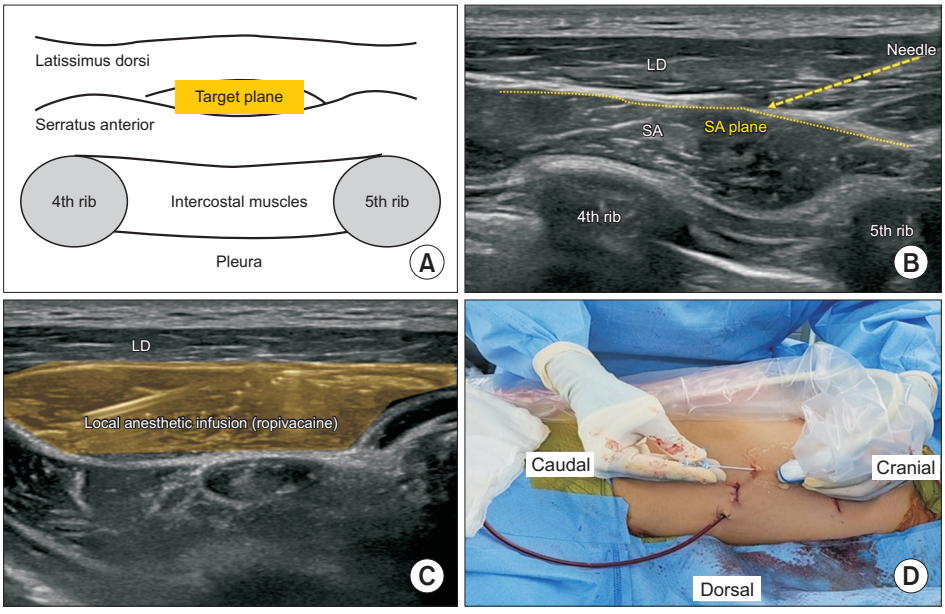

Fig. 2. Intraoperative serratus anterior plane block (SAPB). (A) Illustration of SAPB, showing the injection of local anesthetic agents into the target plane between the serratus anterior (SA) and latissimus dorsi (LD). (B) Ultrasound views of SAPB. A needle (yellow dotted arrow) is targeting the plane between the SA and LD, the hyperechogenic facial plane (yellow dotted line). (C) Hydro-dissection of the SA plane develops the space for catheter placement, and the local anesthetic agent (0.3% ropivacaine) is infused. (D) Bilateral ultrasound-guided Painfusor catheter placement for continuous SAPB after the repair.

pects of the chest wall. Postoperatively, bilateral ultrasound-guided pain fusor catheters (Baxter Inc., Deerfield, IL, USA) were placed for continuous SAPB, with 0.3% ropivacaine infused at a rate of 5 mL/hr (Fig. 2D).

The continuous infusion procedure for SAPB is demonstrated in Supplementary Video 1.

Pain management protocol

Patients in group N received a standardized pain management regimen in accordance with our institutional protocol, which included: (1) IV-PCA, (2) subcutaneous local anesthetic infusion, (3) on-demand nonsteroidal analgesic injections, and (4) oral basal analgesics. Upon initiating IV-PCA with fentanyl at a concentration of 15 μg/kg in 100 mL of normal saline, oral analgesics were administered, specifically ibuprofen at a dosage of 10–15 mg/kg every 6 hours and acetaminophen at the same dosage and frequency. If additional analgesia was required, patients could request ketorolac (0.5 mg/kg) or pethidine (0.5 mg/kg), which were provided as IV rescue analgesics. For the subcutaneous infusion of local anesthetics, catheters measuring either 7.5 cm or 15 cm were placed bilaterally along the posterior axillary lines following surgical repairs. These catheters were connected to a 240-mL reservoir that dispensed 0.3% ropivacaine at a constant rate of 5 mL/hr. The catheters were typically removed 2 to 3 days after surgery. Further details regarding our pain management protocol, which includes general anesthesia, IV-PCA, subcutaneous local anesthetic infusion, and postoperative analgesics, are documented in a previous publication [11].

In group S, continuous SAPB catheters were placed at the interfacial plane of the LD and SA under ultrasound guidance, rather than in the subcutaneous plane. Other than the location of catheter placement, all other treatment modalities were identical in both groups, including the infusion rate (5 mL/hr) and the duration of infusion (2–3 days).

Statistical analysis

Quantitative variables were analyzed using range, mean, and percentage, while categorical variables were assessed using mean, range, and standard deviation. For the comparative analysis of quantitative variables, an independent sample t-test was conducted. The chi-square test was utilized for the comparative analysis of categorical variables, with Fisher's exact test being applied when values were less than 5. All statistical analyses were carried out using IBM SPSS ver. 21.0 software for Windows (IBM Corp., Armonk, NY, USA). The results were interpreted using 95% confidence intervals (CIs), and a p-value <0.05 was deemed statistically significant.

Results

Fifty patients were enrolled in this study, and their baseline characteristics are listed in Table 1. There were no significant differences between the 2 groups in terms of age, height, weight, body mass index, sex, American Society of Anesthesiologists class, or PE type. Perioperative clinical and radiological characteristics are also summarized in Table 1. Although the SAPB procedure added an average of 17 minutes, the mean operative time for group S (110.96 minutes) was comparable to that of group N (125.96 minutes) (p=0.053). All PE repairs were conducted using totally crane-powered surgery, with multiple bar application (cross, parallel, or XI shape) under pectoscopic guidance, bridge plate bar stabilization, and the flare buster/magic string technique.

Pain scores, both resting (VAS-R) or dynamic (VAS-D), were assessed at the anterior (VAS-R-A and VAS-D-A) and lateral (VAS-R-L and VAS-D-L) chest walls (Fig. 3A, B). The mean VAS-R score was significantly lower in group S than in group N for the entire 72-hour postoperative period (p<0.01 in all analyses) (Supplementary Table 1). The VAS-R-A and VAS-R-L scores were lower than 4 at 3 hours postoperatively (3.77 and 3.58, respectively). However, in group N, the VAS-R-A and VAS-R-L scores were greater than 4 during the full 72-hour postoperative period. The VAS-D showed similar results. The mean VAS-D was also significantly lower in group S than in group N for the entire 72-hour postoperative period (p<0.01 in all analyses) (Supplementary Table 2). The dynamic scores in group S became lower than 4 after 24 hours; however, the VAS-D in group N was greater than 4 throughout the full 72-hour postoperative period.

The total postoperative IV analgesic consumption was compared using oral MME values. There were significant differences in total analgesic consumption between the 2 groups (p<0.01 for all tests). Group S demonstrated a statistically significant lower MME during 72 hours postoperatively (group N: 108.53; group S: 16.61; p<0.01) (Table 2).

The postoperative outcomes did not significantly differ between the 2 groups (Table 3). Patients in group S had an average hospital stay of 4.62 days, while those in group N stayed for an average of 4.88 days (p=0.39). There were no complications related to the SAPB, such as toxicity, hema-

Table 1. Baseline characteristics of the study groups

Characteristic	Conventional (group N) (n=24)	SAPB (group S) (n=26)	p-value*
Age (yr)	14.46 (10–20)	14.31 (10–19)	0.83
Height (cm)	166.85 (140–185)	166.35 (131–180)	0.87
Weight (kg)	49.53 (27.0–70.0)	50.17 (28.9–74.0)	0.82
Body mass index (kg/m^2)	17.61 (13.15–22.60)	17.87 (15.78–23.36)	0.67
Male sex	21 (87.5)	21 (80.8)	0.53
ASA class			0.18
ASA I	20 (83.3)	25 (96.2)	
ASA II	4 (16.7)	1 (3.8)	
PE symmetric type	13 (54.2)	17 (65.4)	0.16
Depression index			
Preoperative	1.66 (1.22–2.50, 0.31)	1.62 (1.32–2.56, 0.28)	0.34
Postoperative	1.04 (1.00–1.10, 0.05)	1.02 (1.00–1.07, 0.02)	0.234
Δ Depression index	0.62 (0.17–1.42, 0.31)	0.60 (0.26–1.56, 0.28)	0.932
Operative time (min)	124.86 (70–155)	110.96 (75–180)	0.053
Block time (min)	-	17.77 (14–30, 3.39)	
No. of pectus bars			0.34
1	0	0	
2	3 (12.5)	1 (3.8)	
3	21 (87.5)	25 (96.2)	
Pectus bar pattern			0.32
Parallel	3 (12.5)	3 (11.54)	
Cross	2 (8.3)	0	
XI	19 (79.2)	23 (88.46)	
Crane application	24 (100.0)	26 (100.0)	1.00
Pectoscope	24 (100.0)	26 (100.0)	1.00
Flare buster	24 (100.0)	26 (100.0)	1.00
Magic string	24 (100.0)	26 (100.0)	1.00
Bridge	24 (100.0)	26 (100.0)	1.00

Values are presented as mean (range), number (%), or mean (range, standard deviation).
SAPB, serratus anterior plane block; ASA, American Society of Anesthesiologists.
*p<0.05 (statistically significant).

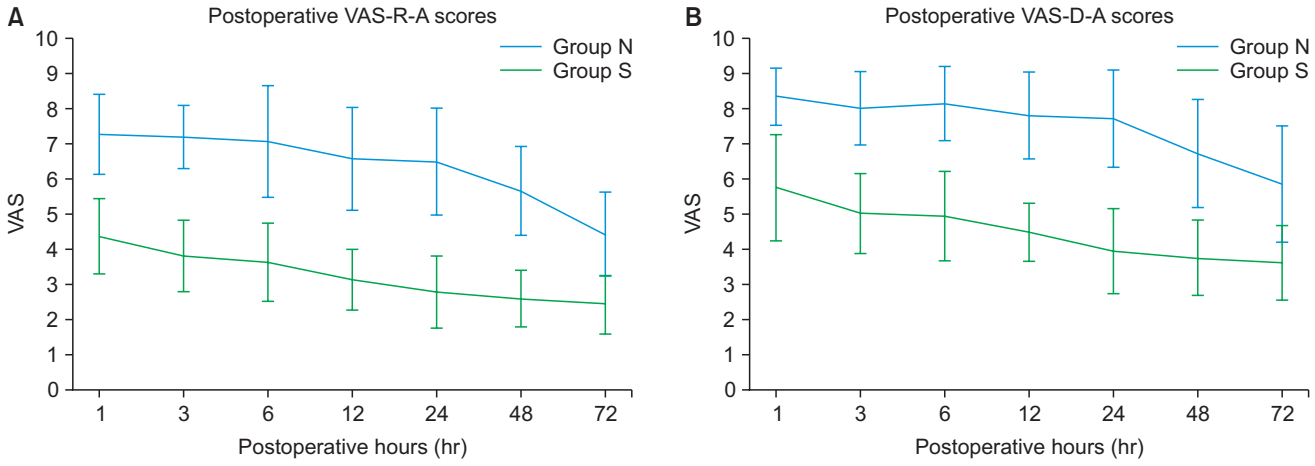

Fig. 3. Visual Analog Scale (VAS) scores for postoperative pain evaluation. (A) Postoperative pain scale at the anterior chest wall in the resting state (VAS-R-A scores) in groups N and S. (B) Postoperative pain scale at the anterior chest wall in the dynamic state (VAS-D-A scores) in groups N and S.

https://doi.org/10.5090/jcs.23.139

Table 2. Total postoperative intravenous rescue analgesic consumption (conversion to oral MME) in the study groups

Oral MME (hr)	Conventional (group N) (n=24)	SAPB (group S) (n=26)	p-value*
6	23.18±10.09	14.63±3.59	<0.01
12	42.99±15.70	15.62±4.15	<0.01
24	67.59±24.97	16.01±4.34	<0.01
48	89.67±39.82	16.24±4.35	<0.01
72	108.53±49.11	16.61±4.96	<0.01

Values are presented as mean±standard deviation.
MME, morphine milligram equivalent; SAPB, serratus anterior plane block.
*p<0.05 (statistically significant).

Table 3. Postoperative outcomes in the study groups

Variable	Conventional (group N) (n=24)	SAPB (group S) (n=26)	p-value*
Length of stay (day)	4.88 (4–8. 1.15)	4.62 (4–7, 0.94)	0.39
Complications			
SAPB-related	0	0	1.00
Pneumothorax	4 (16.7)	3 (11.5)	0.69
Wound infection	1 (4.2)	0	0.48
Pneumonia	0	1 (3.8)	0.45
Thoracic outlet syndrome	0	1 (3.8)	0.45
Bar dislocation	0	0	1.00
Re-operation	0	0	1.00

Values are presented as mean (range, standard deviation) or number (%).
SAPB, serratus anterior plane block.
*p<0.05 (statistically significant).

toma, or infection, in any of the patients. Four patients in group N and 3 in group S developed postoperative pneumothorax (p=0.70), all of which resolved spontaneously without intervention. One patient in group N experienced a postoperative wound seroma (p=0.48), and 1 patient in group S developed postoperative pneumonia (p=0.45); both were successfully treated with antibiotics. Additionally, 1 patient in group S reported right-arm weakness after surgery, which improved spontaneously (p=0.45).

Discussion

Although various analgesic methods have been proposed, most patients still experience severe pain following PE repair. Surgeons performing MIRPE are particularly concerned about managing postoperative pain. IV-PCA is traditionally established as the primary method for postoperative pain control [19]; however, it is associated with opioid-related side effects, including opioid-induced hyperalgesia, sedation, nausea, and respiratory depression, which can be problematic [7]. Thoracic epidural analgesia is regarded as one of the most effective pain management strategies for adults undergoing thoracic procedures, but it carries risks of catheter-related issues, such as kinking or dislodgement, as well as serious neurological complications [8,20]. Nevertheless, this study supports the superiority of SAPB over conventional pain management techniques. While patients in the conventional group reported pain scores above 4 throughout the entire 72-hour period, those who received SAPB maintained a tolerable state (VAS<4) after surgery, starting from 6 hours postoperatively in a supine position and 24 hours in an upright position.

Cryoanalgesia has been the subject of recent investigation at numerous facilities due to its superior efficacy and reduced hospital stay when compared to traditional pain management techniques [9-11]. However, it necessitates single-lung ventilation via double-lumen intubation, video-assisted intrathoracic procedures, and the use of additional cryoequipment, all of which are invasive and increase both time and cost [11]. In contrast, our SAPB procedures are moderately timed, averaging about 17 minutes, and do not require one-lung ventilation or thoracoscopy.

In previous studies of thoracoscopic surgery, SAPB has been shown to provide better pain control, leading to improved postoperative recovery and reduced opioid con-

sumption. This suggests that SAPB is an effective adjunctive treatment for postoperative analgesia following thoracic surgery [21-24]. Compared to studies on thoracic surgery, there have been fewer reports evaluating SAPB in patients undergoing PE repair [25-27]. Tore Altun et al. [26] demonstrated that bilateral single-injection SAPB in patients undergoing MIRPE reduced pain and opioid use compared to IV-PCA alone during the early postoperative period. However, they did not evaluate the postoperative pain score scale. Instead, they compared the number of times patients pressed the PCA button (demand dose) with the number of times they actually received pain medication (delivered dose) at 24 hours and 48 hours postoperatively. The control group exhibited a higher demand and received a higher delivered dose in the first 24 hours after surgery.

In this study, we evaluated the effectiveness of continuous SAPB for postoperative pain control following PE repair with pectus bars. Our findings indicate that SAPB significantly decreased postoperative pain and reduced the overall consumption of analgesics when compared to traditional pain management methods.

The present study focused on the onset time of the SAPB effect. We observed that the difference was not limited to the 24-hour mark; there was also a notable distinction in the very early phase (3, 6, and 12 hours) that persisted into the delayed phase (48 and 72 hours). Administering a bolus followed by a continuous infusion of local anesthetic agents produces a significant effect from the onset and maintains efficacy throughout the duration of the infusion.

To the best of our knowledge, this is the first retrospective study to examine the effectiveness of continuous SAPB following PE repair, utilizing both resting and dynamic postoperative VAS scores for pain, as well as assessing pain distribution across the anterior and lateral chest. Building on the findings of this study, we intend to carry out a comparative analysis that includes conventional pain management, cryoanalgesia, and SAPB to identify the most effective pain control protocol after MIRPE in the near future.

This study has several limitations. First, this was a retrospective, small-cohort study. Second, we did not analyze long-term data after discharge because prolonged pain can impede a patient's full recovery.

In conclusion, SAPB offers superior pain management in pectus surgery compared to conventional IV-PCA. SAPB improved immediate postoperative pain control during both rest and movement and decreased opioid consumption without causing complications. Large-scale prospective studies are warranted to confirm these preliminary findings.

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Conflict of interest

No potential conflict of interest relevant to this article was reported.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Supplementary materials

Supplementary materials can be found via https://doi.org/10.5090/jcs.23.139. **Supplementary Table 1**. Postoperative VAS-R scores in the study groups. **Supplementary Table 2**. Postoperative VAS-D scores in the study groups. **Supplementary Video 1**. Serratus anterior plane block after pectus excavatum repair.

References

1. Park HJ, Kim KS, Lee S, Jeon HW. A next-generation pectus excavatum repair technique: new devices make a difference. Ann Thorac Surg 2015;99:455-61. https://doi.org/10.1016/j.athoracsur.2014.08.026
2. Park HJ, Jeong JY, Jo WM, et al. Minimally invasive repair of pectus excavatum: a novel morphology-tailored, patient-specific approach.

J Thorac Cardiovasc Surg 2010;139:379-86. https://doi.org/10.1016/j.jtcvs.2009.09.003
3. Nuss D, Obermeyer RJ, Kelly RE. Nuss bar procedure: past, present and future. Ann Cardiothorac Surg 2016;5:422-33. https://doi.org/10.21037/acs.2016.08.05
4. Singhal NR, Jerman JD. A review of anesthetic considerations and postoperative pain control after the Nuss procedure. Semin Pediatr Surg 2018;27:156-60. https://doi.org/10.1053/j.sempedsurg.2018.05.010
5. Weber T, Matzl J, Rokitansky A, et al. Superior postoperative pain relief with thoracic epidural analgesia versus intravenous patient-controlled analgesia after minimally invasive pectus excavatum repair. J Thorac Cardiovasc Surg 2007;134:865-70. https://doi.org/10.1016/j.jtcvs.2007.05.050
6. Soliman IE, Apuya JS, Fertal KM, Simpson PM, Tobias JD. Intravenous versus epidural analgesia after surgical repair of pectus excavatum. Am J Ther 2009;16:398-403. https://doi.org/10.1097/mjt.0b013e318187de3e
7. Heo MH, Kim JY, Kim JH, et al. Epidural analgesia versus intravenous analgesia after minimally invasive repair of pectus excavatum in pediatric patients: a systematic review and meta-analysis. Korean J Anesthesiol 2021;74:449-58. https://doi.org/10.4097/kja.21133
8. Sujka JA, Dekonenko C, Millspaugh DL, et al. Epidural versus PCA pain management after pectus excavatum repair: a multi-institutional prospective randomized trial. Eur J Pediatr Surg 2020;30:465-71. https://doi.org/10.1055/s-0039-1697911
9. Morikawa N, Laferriere N, Koo S, Johnson S, Woo R, Puapong D. Cryoanalgesia in patients undergoing Nuss repair of pectus excavatum: technique modification and early results. J Laparoendosc Adv Surg Tech A 2018;28:1148-51. https://doi.org/10.1089/lap.2017.0665
10. Arshad SA, Hatton GE, Ferguson DM, et al. Cryoanalgesia enhances recovery from minimally invasive repair of pectus excavatum resulting in reduced length of stay: a case-matched analysis of NSQIP-Pediatric patients. J Pediatr Surg 2021;56:1099-102. https://doi.org/10.1016/j.jpedsurg.2021.03.017
11. Rim GM, Kim HK, Koo JM, Park HJ. A randomized controlled trial of cryoanalgesia for pain management following pectus excavatum repair: a single-center, single-blind, parallel design study. Eur J Pediatr Surg 2023 Aug 31 [Epub]. https://doi.org/10.1055/a-2117-4628
12. Blanco R, Parras T, McDonnell JG, Prats-Galino A. Serratus plane block: a novel ultrasound-guided thoracic wall nerve block. Anaesthesia 2013;68:1107-13. https://doi.org/10.1111/anae.12344
13. Khanna G, Jaju A, Don S, Keys T, Hildebolt CF. Comparison of Haller index values calculated with chest radiographs versus CT for pectus excavatum evaluation. Pediatr Radiol 2010;40:1763-7. https://doi.org/10.1007/s00247-010-1681-z
14. Park HJ, Rim G. Development of a screw-crane system for pre-lifting the sternal depression in pectus excavatum repair: a test of mechanical properties for the feasibility of a new concept. J Chest Surg 2021;54:186-90. https://doi.org/10.5090/jcs.21.008
15. Park HJ, Kim KS. The sandwich technique for repair of pectus carinatum and excavatum/carinatum complex. Ann Cardiothorac Surg 2016;5:434-9. https://doi.org/10.21037/acs.2016.08.04
16. Park HJ. A technique for complex pectus excavatum repair: the cross-bar technique for grand canyon type deformity (Park classification). Ann Cardiothorac Surg 2016;5:526-7. https://doi.org/10.21037/acs.2016.08.01
17. Baytar MS, Yilmaz C, Karasu D, Baytar C. Comparison of ultrasonography guided serratus anterior plane block and thoracic paravertebral block in video-assisted thoracoscopic surgery: a prospective randomized double-blind study. Korean J Pain 2021;34:234-40. https://doi.org/10.3344/kjp.2021.34.2.234
18. Chen JQ, Yang XL, Gu H, Chai XQ, Wang D. The role of serratus anterior plane block during in video-assisted thoracoscopic surgery. Pain Ther 2021;10:1051-66. https://doi.org/10.1007/s40122-021-00322-4
19. Dekonenko C, Dorman RM, Duran Y, et al. Postoperative pain control modalities for pectus excavatum repair: a prospective observational study of cryoablation compared to results of a randomized trial of epidural vs patient-controlled analgesia. J Pediatr Surg 2020;55:1444-7. https://doi.org/10.1016/j.jpedsurg.2019.09.021
20. Jaroszewski DE, Temkit M, Ewais MM, et al. Randomized trial of epidural vs. subcutaneous catheters for managing pain after modified Nuss in adults. J Thorac Dis 2016;8:2102-10. https://doi.org/10.21037/jtd.2016.06.62
21. Hu NQ, He QQ, Qian L, Zhu JH. Efficacy of ultrasound-guided serratus anterior plane block for postoperative analgesia in patients undergoing breast surgery: a systematic review and meta-analysis of randomised controlled trials. Pain Res Manag 2021;2021:7849623. https://doi.org/10.1155/2021/7849623
22. Park MH, Kim JA, Ahn HJ, Yang MK, Son HJ, Seong BG. A randomised trial of serratus anterior plane block for analgesia after thoracoscopic surgery. Anaesthesia 2018;73:1260-4. https://doi.org/10.1111/anae.14424
23. Semyonov M, Fedorina E, Grinshpun J, et al. Ultrasound-guided serratus anterior plane block for analgesia after thoracic surgery. J Pain Res 2019;12:953-60. https://doi.org/10.2147/jpr.s191263
24. Viti A, Bertoglio P, Zamperini M, et al. Serratus plane block for video-assisted thoracoscopic surgery major lung resection: a randomized controlled trial. Interact Cardiovasc Thorac Surg 2020;30:366-72. https://doi.org/10.1093/icvts/ivz289
25. He Y, Xu M, Jiang X, Li Z, Du B. Comparing postoperative analgesia of bilateral serratus anterior plane block and thoracic paravertebral block for children following the Nuss procedure: protocol for a randomised, double-blind, non-inferiority clinical trial. BMJ Paediatr Open 2023;7:e002128. https://doi.org/10.1136/bmjpo-2023-002128
26. Tore Altun G, Arslantas MK, Corman Dincer P, Aykac ZZ. Ultrasound-guided serratus anterior plane block for pain management fol-

lowing minimally invasive repair of pectus excavatum. J Cardiothorac Vasc Anesth 2019;33:2487-91. https://doi.org/10.1053/j.jvca.2019.03.063

27. Downing L, Ramjist JK, Tyrrell A, Tsang M, Isaac L, Fecteau A. Development of a five point enhanced recovery protocol for pectus excavatum surgery. J Pediatr Surg 2023;58:822-7. https://doi.org/10.1016/j.jpedsurg.2023.01.028