

A Comparative study on the analgesic efficacy of ultrasound-guided bilateral Pecto-intercostal fascial block with an ultrasound-guided caudal block in Pediatric patients undergoing congenital cardiac surgeries – A randomised double blind study

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Type of Publication: Original Research Article

Conflicts of Interest: Nil

Abstract

Objectives: This study compared the analgesic efficacy and hemodynamic effects of PIFB versus caudal block in children undergoing cardiac surgery via median sternotomy.

Design: A single centre prospective double blind randomized controlled trial.

Setting: study was conducted in a tertiary care cardiac centre.

Participants: 59 children undergoing cardiac surgery through median sternotomy were included.

Interventions: Participants were randomized to receive either PIFB (n = 29) or caudal block (n = 30).

Measurements and main results: Hemodynamic parameters, FLACC pain scores, fentanyl consumption, inotropic requirements, time to first rescue analgesia, number of rescue doses, and extubation times were recorded.

Baseline demographics were comparable between groups. The PIFB group demonstrated lower intraoperative HR and more stable MAP during sternotomy and skin incision ($p < 0.01$). Postoperative pain scores were significantly lower at 4, 6 and 8 hours ($p < 0.001$). Time to first rescue analgesia was longer with PIFB (5.5 ± 1.8 vs. 3.9 ± 1.5 hours; $p = 0.001$), with fewer rescue doses [PIFB 1.0 (1.0-2.0) vs. caudal 2.0 (2.0-3.0)]; $p = 0.002$) and reduced fentanyl consumption [PIFB 11.5 (11.5-13.5) vs. caudal 13.0 (12.0-14.0) $\mu\text{g/kg}$; $p < 0.001$]. VIS scores and CVP were similar with no block related complications. Extubation was slightly earlier in the PIFB group ($p = 0.05$).

Conclusion: PIFB resulted in effective analgesia, better hemodynamic stability, and reduced opioid requirement compared with caudal block, supporting its use in pediatric cardiac enhanced recovery protocols.

Keywords: PIFB, Caudal Epidural, Pediatric Cardiac Surgery, Regional Anesthesia, Analgesia, Congenital Heart Surgery.

Introduction

Effective pain management in pediatric cardiac surgery is essential to improve outcomes and reduce perioperative morbidity. However, misconceptions such as “children do not perceive pain like adults” continue to hinder optimal analgesia¹. Inadequate pain control can

lead to central sensitization, potentially increasing the risk of chronic postsurgical pain (CPSP)². Although CPSP is less common in children than adults, a Danish study reported a prevalence of up to 21% in pediatric cardiac surgery patients.³ Optimal acute pain control during the perioperative period is crucial to reduce CPSP risk. Systemic opioids remain the cornerstone of analgesia for pediatric sternotomy, but there is no consensus on optimal dosing to balance effective analgesia and side effects⁴. Moreover, inadequate analgesia can amplify the surgical stress response—a complex cascade of neurohumoral, metabolic, immunologic, and endocrine changes—resulting in significant physiological disturbances.⁵ These responses contribute to postoperative organ dysfunction, prolonged mechanical ventilation, increased Intensive Care Unit (ICU) and hospital stays, and overall higher morbidity⁶. Regional anesthesia offers a promising adjunct to attenuate both pain and the stress response. The caudal epidural block is a commonly used technique in pediatric cardiac surgery. Despite its widespread use, achieving the high dermatomal coverage necessary for sternotomy may require large volumes (up to 1.6 mL/kg), raising concerns about hemodynamic fluctuations and elevated intracranial pressure⁷. While ultrasound (US)-guided techniques improve accuracy, the quality of evidence supporting caudal blocks in this context remains suboptimal, as highlighted by Maharramova and Taylor in a systematic review⁸.

In recent years, ultrasound-guided fascial plane blocks have gained traction as safer and effective alternatives. The parasternal intercostal plane (PIP) block, specifically its superficial variant—the Pecto-Intercostal Fascial Block (PIFB)—provides multi-level analgesia with a single injection, can be performed in the supine

position, and avoids deeper structures such as the pleura, vessels, and heart⁹. This makes it particularly attractive in pediatric patients. Given these considerations, this study aims to compare the efficacy of ultrasound-guided PIFB with ultrasound-guided caudal epidural block in pediatric patients undergoing cardiac surgery via midline sternotomy.

Methods

Primary objective: The primary outcome was cumulative perioperative fentanyl consumption, defined as the total fentanyl administered from induction of anesthesia until completion of the 12 hours post-extubation.

Secondary objective: Secondary outcomes included postoperative pain scores during the first 12 hours after extubation, time to extubation, time to first rescue analgesia, number of rescue analgesic episodes, and adverse events.

Study Setting and Design

Regulatory approval: The study was conducted at the Dept. of Paediatric Cardiac Anesthesia, in a tertiary care cardiac Centre, after approval from the Institutional Ethics Committee. The study was registered in CTRI (CTRI/2024/12/078696) before recruitment of the study participants.

Study design: A Prospective randomised controlled study.

Sample size: As no previous pediatric studies directly comparing pecto-intercostal fascial block (PIFB) with caudal epidural analgesia for median sternotomy were available at the time of study design, sample size estimation was based on data obtained from a preliminary pilot study conducted at our institution. The pilot study included 20 children (10 in each group) undergoing pediatric cardiac surgery, who used the same

surgical, anaesthetic, and perioperative analgesic protocol as in the present trial.

The primary outcome for sample size estimation was cumulative perioperative fentanyl consumption. Mean cumulative fentanyl consumption was 22.6 ± 15.42 $\mu\text{g/kg}$ in the caudal group and 11.3 ± 7.71 $\mu\text{g/kg}$ in the PIFB group. Using a two-sided α of 0.05 and 80% power, the minimum required sample size was 19 patients per group, calculated using the formula for comparison of two independent means:
$$n = 2(Z_{\alpha/2} + Z_{\beta})^2 \sigma^2 / \Delta^2$$

Where $Z_{\alpha/2} = 1.96$, $Z_{\beta} = 0.84$, σ is the pooled standard deviation, and Δ is the expected mean difference between groups.

Although the minimum calculated sample size was 19 patients per group, the recruitment target was set at 30 patients per group to improve the precision of the estimated treatment effect and allow for potential exclusions or protocol deviations. Sixty patients were assessed for eligibility; one declined participation before randomization, resulting in 59 randomized participants (29 PIFB and 30 caudal).

Sample size was calculated using OpenEpi (Version 3.01).

Inclusion criteria

Patients aged 6 months to 7 years undergoing elective congenital cardiac surgery requiring median sternotomy and Cardio Pulmonary Bypass (CPB) were included in the study.

Exclusion criteria

- Patients with RACHS (Risk Adjusted classification for Congenital Heart Surgery) score > 3
- Emergency surgeries
- Chest wall deformities

- d. Anorectal malformations
- e. Subjects allergic to local anaesthetics
- f. Evidence of Coagulopathy
- g. Patients on anticoagulants
- h. Localized infection

Patients were randomized using a computer-generated sequence generated by an independent investigator. Allocation was concealed using sequentially numbered, opaque, sealed envelopes, and postoperative assessments were performed by a blinded investigator.

1. Group I - (General anaesthesia (GA) + U/S guided PIFB)
2. Group II - (General anaesthesia (GA) + Caudal block)

Study procedure: On the day of the surgery, intravenous access was established, and standard monitoring including pulse oximetry, continuous electrocardiography (ECG), arterial blood pressure and central venous pressure monitoring was initiated. General anaesthesia was administered with endotracheal intubation and controlled ventilation. All subjects received a standardised protocol for anaesthesia induction and maintenance. Induction was achieved with ketamine 2 mg/kg, glycopyrrolate 0.01 mg/kg, Fentanyl 2 µg/kg and rocuronium 1 mg/kg, while vecuronium was used as a maintenance muscle relaxant until the completion of surgery. Anaesthesia was maintained with sevoflurane at 0.6–0.8 MAC and dexmedetomidine infusion at 0.5 µg/kg/hr in both groups.

In Group I, the pecto-intercostal fascial block (PIFB) was performed in the supine position using an in-plane approach with a high-frequency (12 MHz) linear ultrasound transducer (Fujifilm Sonosite EDGE II L25XP, Bothell, WA, USA). Under strict aseptic precautions, the pecto-intercostal fascial plane was

identified, and saline hydrodissection was performed to confirm the correct plane, followed by injection of bupivacaine 2.5 mg/kg (0.25%) and fentanyl 1 µg/kg under ultrasound visualization(fig1). A total volume of 1 mL/kg was administered, distributed equally between both pecto-intercostal fascial planes (0.5 mL/kg per side).

In Group II, the caudal block was performed in the lateral recumbent position. After identifying the sacral hiatus using an ultrasound-guided in-plane approach under aseptic conditions, bupivacaine 2.5 mg/kg (0.2%) and fentanyl 1 µg/kg were injected into the caudal epidural space(fig2). A total volume of 1.5 mL/kg was administered. The surgical incision was made 20 minutes after the administration of the local anesthetic in both groups. Following the caudal block, a minimum interval of one hour was maintained before heparin administration for cannulation.

An additional bolus of fentanyl (2 µg/kg) was given if the heart rate or mean arterial pressure (MAP) increased by more than 20% from baseline at skin incision or during sternotomy. After weaning from cardiopulmonary bypass and modified ultrafiltration, if MAP exceeded the age-appropriate range, an additional fentanyl dose of 1 µg/kg was administered. As per institutional protocol, fentanyl 1 µg/kg, vecuronium 0.1 mg/kg, and midazolam 0.05 mg/kg were added to the pump prime during establishment of cardiopulmonary bypass and during rewarming. Total intraoperative fentanyl consumption was recorded in both groups.

Definition of total fentanyl consumption: Cumulative perioperative fentanyl consumption included fentanyl administered during anesthetic induction, fentanyl added to the regional block, fentanyl added to the cardiopulmonary bypass pump prime, supplemental

intraoperative fentanyl boluses, and postoperative rescue fentanyl. Induction fentanyl, regional block fentanyl, and CPB pump fentanyl were administered according to a standardized protocol and were identical in both groups; therefore, any between-group difference in cumulative fentanyl consumption primarily reflected differences in supplemental intraoperative and postoperative opioid requirements.

The vasoactive-inotropic score (VIS) was calculated using the formula:

$$\text{VIS} = [\text{dopamine } (\mu\text{g}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}) + \text{dobutamine } (\mu\text{g}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}) + 100 \times \text{epinephrine } (\mu\text{g}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}) + 100 \times \text{norepinephrine } (\mu\text{g}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}) + 10 \times \text{milrinone } (\mu\text{g}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}) + 10,000 \times \text{vasopressin } (\text{units}\cdot\text{kg}^{-1}\cdot\text{min}^{-1})].$$

The duration of mechanical ventilation was recorded. Post-extubation pain was assessed using the FLACC (Face, Legs, Activity, Cry, Consolability) scale every two hours for the first 12 hours. The time to first rescue analgesia (minutes) and the number of rescue analgesic episodes were documented. All adverse events, including pruritus, respiratory depression, or vomiting, were noted. All patients received intravenous paracetamol 15 mg/kg every 8 hours postoperatively until chest drains were removed.

Criteria for first rescue analgesia

If the FLACC score exceeded 4, fentanyl 1 µg/kg was administered intravenously. Pain was reassessed 30 minutes later, and if the FLACC score remained >4, an additional dose of fentanyl 0.5 µg/kg was given.

The anesthesiologist performing the regional block was not involved in intraoperative management or postoperative pain assessment. ICU staff assessing pain scores and administering rescue analgesia were blinded to group allocation.”



Fig. 1: Ultrasound guided Pecto-intercostal fascial block



Fig. 2: Ultrasound guided caudal block

A total of 59 patients were included in the study, with 29 patients in the PIFB group and 30 patients in the caudal group. The demographic characteristics (age & sex distribution) were comparable between the two groups.

Assessed for eligibility (n=60)

|

Excluded (n=1)

• Declined consent (n=1)

|

Randomized (n=59)

/

Allocated to	Allocated to
PIFB (n=29)	Caudal (n=30)

|

Received allocated	Received allocated
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intervention (n=29)	intervention (n=30)
Lost to follow-up (n=0)	Lost to follow-up (n=0)
Discontinued intervention (n=0)	Discontinued intervention (n=0)
Analyzed (n=29)	Analyzed (n=30)

Statistical Analysis

Data were analyzed using appropriate descriptive and inferential statistical methods. Normality of continuous variables was assessed using the Shapiro–Wilk test. Most hemodynamic variables (heart rate, mean arterial pressure, and central venous pressure) demonstrated mixed distributions across time points. Pain scores and total fentanyl consumption were predominantly non-normally distributed, whereas time to first rescue analgesia and time to extubation were normally distributed.

Normally distributed variables were expressed as mean $\pm$ standard deviation (SD) and compared using the independent Student's t-test. Non-normally distributed variables were presented as median with interquartile range (IQR) and compared using the Mann–Whitney U test. Categorical variables were expressed as frequencies and percentages and compared using the chi-square test or Fisher's exact test, as appropriate.

Pain scores, being ordinal, were analyzed using non-parametric methods. Between-group comparisons at individual time points were performed using the Mann–Whitney U test. Within-group changes over time for

hemodynamic variables were analyzed using the Friedman test.

No missing outcome data were observed, and therefore no imputation was performed.

A p-value < 0.05 was considered statistically significant. Statistical analysis was performed using IBM SPSS Statistics for Windows, Version 29.0 (IBM Corp., Armonk, NY, USA).

Results

Sixty patients were assessed for eligibility. One patient declined to participate before randomization. Consequently, 59 patients were randomized, with 29 allocated to the PIFB group and 30 to the caudal epidural group. All randomized patients completed follow-up and were included in the final analysis.

Hemodynamic Parameters

Hemodynamic variables were analyzed as repeated measures within each treatment group using the Friedman test. When the Friedman test was significant, post hoc pairwise comparisons were performed using the Durbin–Conover test with adjustment for multiple comparisons. Between-group comparisons at each perioperative time point were performed using the Mann–Whitney U test because several measurements demonstrated non-normal distributions.

Heart Rate (HR): Intraoperative heart rate was significantly lower in the PIFB group at several time points during the surgery. Prior to skin incision, HR was significantly lower in the PIFB group (86.34 ± 6.91 bpm) compared to the caudal group (92.63 ± 10.78 bpm; $p = 0.010$). Similar trends were observed 1 minute after skin incision ($p = 0.003$), 1 minute before sternotomy ($p < 0.001$), 1 minute after sternotomy ($p < 0.001$), and post-MUF ($p < 0.001$).

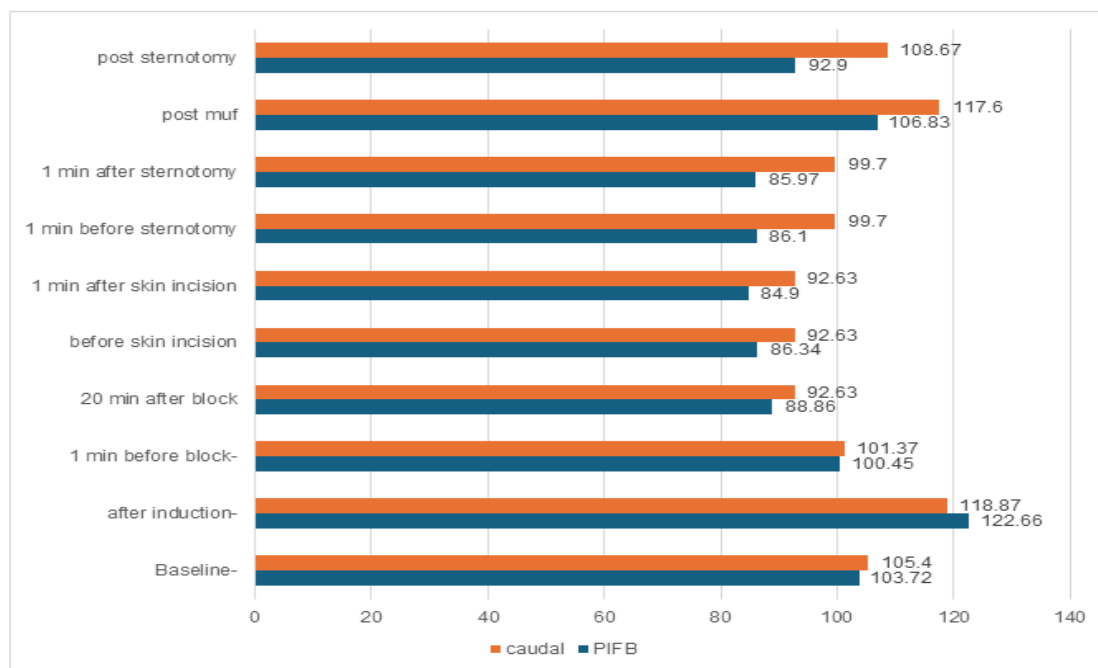


Figure 1: Heart rate (HR) comparison between the two groups

Mean Arterial Pressure (MAP): MAP was also more stable in the PIFB group. Notably, MAP was significantly higher in the PIFB group at 1 minute after skin incision (71.86 ± 7.70 mmHg vs 65.27 ± 10.24 mmHg; $p = 0.007$), 1 minute before sternotomy ($p = 0.009$), 1 minute after sternotomy ($p = 0.008$), post-MUF ($p < 0.001$), and post-sternotomy closure ($p < 0.001$).

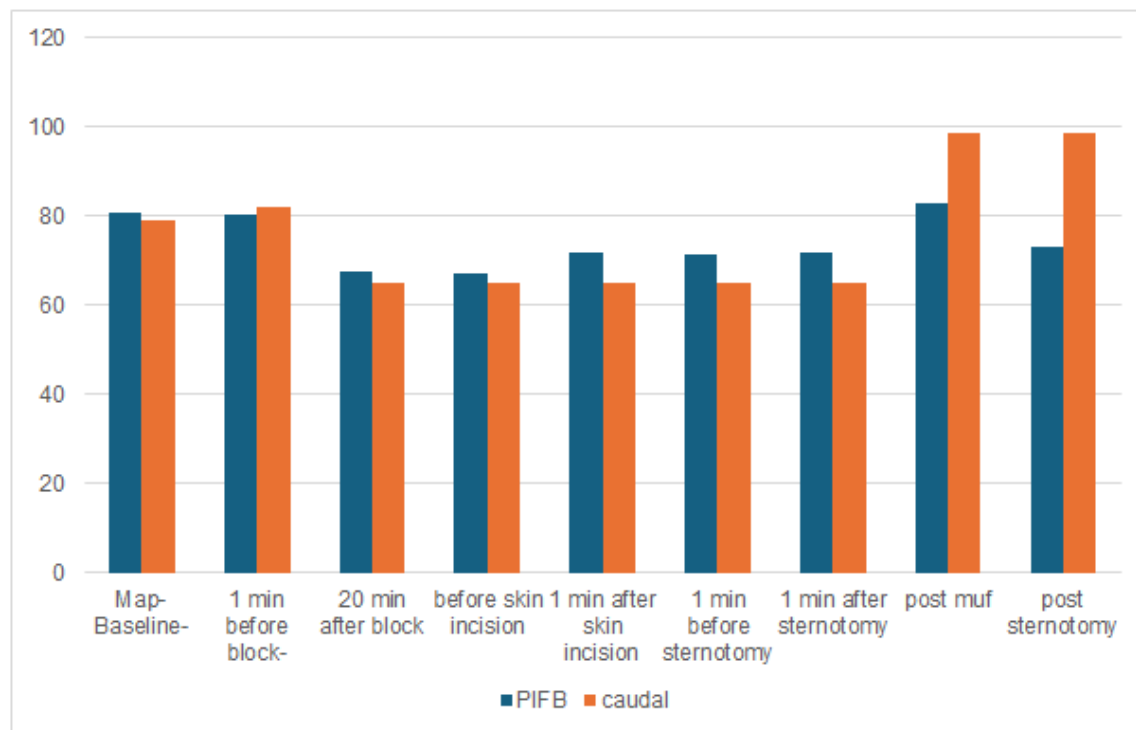


Figure 2: Mean arterial pressure (MAP) comparison between the two groups.

Central Venous Pressure (CVP): There was no statistically significant difference in CVP measurements between the PIFB and caudal groups at all measured time points ($p > 0.05$).

Pain Scores

Postoperative pain scores were significantly lower in the PIFB group at multiple time intervals. At 4 hours

postoperatively, the pain score was 3.17 ± 1.10 in the PIFB group versus 5.37 ± 1.67 in the caudal group ($p < 0.001$). This trend continued at 6 hours ($p < 0.001$), 8 hours ($p < 0.001$), 10 hours ($p = 0.039$), and 12 hours ($p = 0.039$). Pain scores at 30 minutes and 2 hours postoperatively were comparable between the groups.

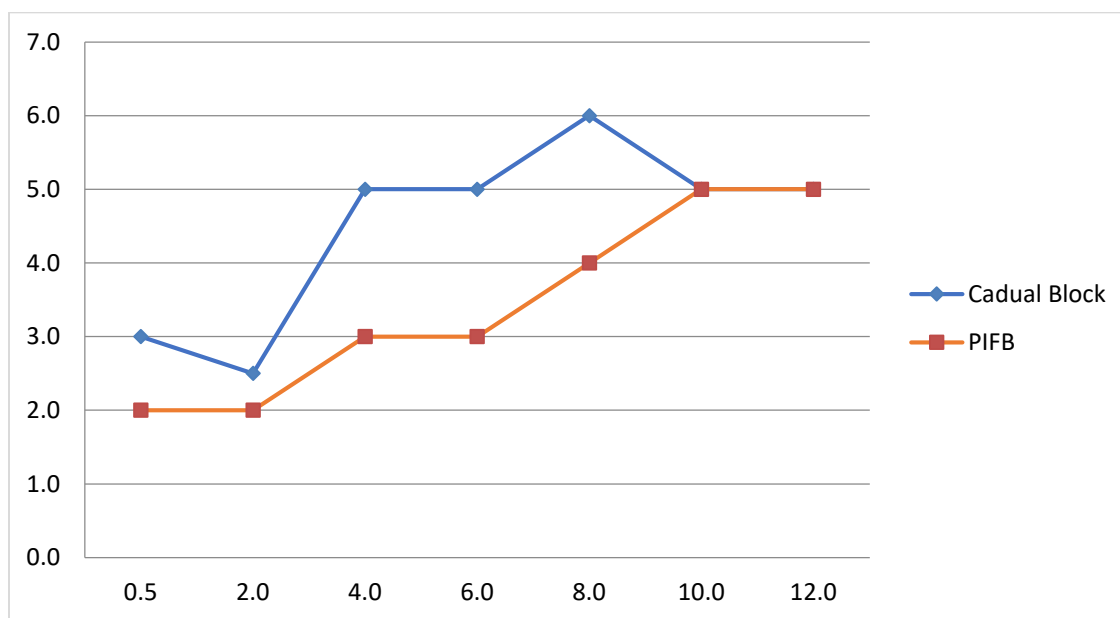


Figure 3: Pain scores comparison between the two groups; values are expressed as median (IQR)

Analgesic Requirements

The time to first rescue analgesia was significantly longer in the PIFB group (5.45 ± 1.82 hours) compared to the caudal group (3.86 ± 1.48 hours; $p = 0.001$). The number of rescue analgesia episodes was significantly lower in the PIFB group than in the caudal group (median 1 [IQR 1–2] vs 2 [IQR 2–3], $p = 0.002$).

Total fentanyl consumption (cumulative intraoperative and postoperative rescue doses) was significantly reduced in the PIFB group, 11.5 (11.5-13.5) compared to the caudal group 13.0 (12.0-14.0); $p < 0.001$.

Table 1: Illustrates Total fentanyl consumption between the two groups

	Group	N	Median (IQR)	Mann-Whitney P-Value
Total fentanyl consumption in mcg/kg	Caudal Block	30	13.0 (12.0-14.0)	<0.001
	PIFB	29	11.5 (11.5-13.5)	

Table 2: Illustrates the Effect size regarding the total fentanyl consumption.

		Statistic	p		Effect Size
Total fentanyl consumption in mcg/kg	Mann-Whitney U	70.5	<0.001	Rank biserial correlation	0.84

Time to Extubation

Time to extubation was shorter in the PIFB group (273 ± 27 vs 284 ± 47 minutes), although the difference was borderline and did not reach statistical significance ($p = 0.050$).

Vasoactive-Inotropic Score

There was no statistically significant difference in the inotropic score between the two groups at the evaluated time points. The mean inotropic score after modified ultrafiltration (MUF) was 7.66 ± 3.42 in the PIFB group and 7.87 ± 2.30 in the caudal group ($p = 0.781$).

Similar findings were observed post-sternum closure with identical mean scores and p-values, indicating comparable requirements for inotropic support intraoperatively.

Adverse events

Table 3: Incidence of adverse events between the two groups

Adverse event	Group I (PIFB)	Group II (Caudal)
PONV	1	1
Pruritus	0	0
Respiratory depression	0	0

Discussion

In the current era of Enhanced Recovery After Surgery (ERAS) in pediatric cardiac surgery, early postoperative rehabilitation and opioid minimization are essential goals. Regional anesthesia techniques are pivotal in opioid-sparing analgesia (OSA) protocols across various surgical domains¹⁰. While caudal epidural blocks have long been the standard in pediatric patients, the advent of ultrasound guidance has led to the growing use of fascial plane blocks. In this study, we compared ultrasound-guided Pecto-Intercostal Fascial Block (PIFB) with ultrasound-guided caudal epidural block for

perioperative analgesia in children undergoing cardiac surgery via midline sternotomy.

Originally described by De la Torre for breast surgeries, the PIFB targets the anterior cutaneous branches of T2–T6, effectively covering the parasternal area and sternotomy site¹¹. The block involves local anesthetic injection between the pectoralis major and intercostal muscles. It is technically simple, performed in the supine position, and avoids the deeper anatomical risks associated with thoracic paravertebral blocks. Although pediatric data are limited, studies like that of Jaya AAGPS et al. suggest that bilateral PIFB is safe and effective in managing sternotomy-related pain in children.¹²

In our study, a combination of local anesthetics and opioids was used in both groups to achieve a synergistic analgesic effect, where local anesthetics block nerve conduction and opioids inhibit neurotransmitter (substance P) release at the dorsal horn. This approach allowed for lower doses of each agent, enhancing efficacy while minimizing side effects¹³.

Hemodynamics

One of the most prominent findings was the improved intraoperative hemodynamic profile in the PIFB group. Both heart rate (HR) and mean arterial pressure (MAP) were significantly more stable, particularly from the time of incision through post-modified ultrafiltration(MUF) and sternal closure. This aligns with findings by Ahmed SG et al., who reported lower HR and MAP in the PIFB group compared to Intravenous fentanyl in pediatric cardiac patients¹⁴. In contrast, the caudal group exhibited higher heart rate and lower mean arterial pressure at several intraoperative time points. The hemodynamics are more varied in caudal as shown in different studies, particularly with certain drugs like bupivacaine and

morphine⁸. A possible explanation is the wider cephalad spread of local anesthetic following caudal epidural administration, resulting in greater sympathetic blockade and consequent vasodilation, which may contribute to lower MAP and compensatory tachycardia. However, sympathetic activity was not directly measured in the present study; therefore, this explanation remains speculative. Alternatively, differences in dermatomal coverage and analgesic efficacy between the two techniques may also have contributed to the observed hemodynamic differences. The targeted nature of PIFB reduces sympathetic involvement, thereby enhancing hemodynamic control.

These findings support the notion that regional techniques addressing anterior thoracic dermatomes, particularly when guided by ultrasound, are better suited to blunt the perioperative stress response than lower neuraxial techniques such as caudal epidural block.

Pain scores

Pain scores in the PIFB group were significantly lower at 4, 6, 8, 10, and 12 hours. Pain scores at 30 minutes and 2 hours post-extubation were comparable. Similar results were reported by Ahmed SG et al., who noted lower pain scores in the PIFB group at multiple postoperative intervals with comparable pain scores at 1 hour post-extubation¹⁴.

Zhang et al. also reported reduced pain for up to 24 hours, and Einhorn et al. found lower scores during the first 12 hours postoperatively^{15,16}. These findings reinforce PIFB's prolonged analgesic effect, which is particularly valuable in preventing long-term sensitization and chronic postsurgical pain (CPSP) in children.

Opioid consumption and rescue analgesia

PIFB showed a significant opioid-sparing effect in our study. The number of rescue analgesia episodes was significantly lower in the PIFB group than in the caudal group (median 1 [IQR 1–2] vs 2 [IQR 2–3], $p = 0.002$), had a longer interval before the first rescue analgesic (5.45 ± 1.82 hours) compared to the caudal group (3.86 ± 1.48 hours; $p = 0.001$), and received significantly less cumulative fentanyl 11.5 (11.5–13.5) compared to the caudal group 13.0 (12.0–14.0); $p < 0.001$). These results are consistent with previous studies:

Ahmed SG et al. reported higher cumulative fentanyl use in controls versus PIFB¹⁴.

Zhang et al. demonstrated significant reduction of intraoperative fentanyl (13.3 ± 1.7) PIFB versus control group (19.9 ± 2.2 $\mu\text{g/kg}$), $p < 0.01$, as well as postoperative total fentanyl consumption (1.4 ± 0.4 vs 3.8 ± 1.3 $\mu\text{g/kg}$), $p < 0.01$ ¹⁶.

Einhorn et al. found in their study that PIFB + rectus sheath block patients had lower opioid consumption than those in the local infiltration group (0.27 ± 0.2 oral morphine milligram equivalents per kilogram (OME/kg) vs 0.64 ± 0.42 OME/kg), with an estimated decrease of 0.39 OME/kg (95% CI $-0.52, -0.25$; $p < 0.001$) following overlap propensity score weighting.¹⁶

Notably, our study adds new evidence by documenting both the frequency and timing of rescue analgesia administration, which are not typically reported in prior studies.

Although the absolute reduction in fentanyl consumption was modest, it was accompanied by improved pain control, fewer rescue analgesic interventions, and earlier extubation, supporting the overall clinical benefit of the opioid-sparing strategy. Cumulative fentanyl

consumption was selected as the primary endpoint to quantify overall perioperative opioid exposure. Although intraoperative and postoperative opioid requirements may reflect different clinical processes, cumulative exposure provides a pragmatic measure of the overall opioid requirement associated with each analgesic strategy.

Therefore, total fentanyl consumption provided a valid and meaningful summary measure for the study objective. Furthermore, reduced opioid use aligns with the goals of enhanced recovery protocols, promoting faster rehabilitation and shorter ICU stays.

Extubation and Recovery

Time to extubation was 11 minutes shorter in the PIFB group; however, given the modest absolute difference, the clinical significance of this finding remains uncertain.

Zhang et al. similarly reported decreased time to extubation (33.2 ± 9.7) compared to the control group time (75.7 ± 9.6) $p < 0.01$ [15]. While Einhorn et al. found no difference, though their measure included total anesthesia time, not just post-operative time¹⁶. This early extubation benefit likely results from the combination of reduced pain, improved hemodynamics, and decreased opioid burden associated with PIFB.

Safety: Central Venous Pressure (CVP) and Inotropic Requirements

Both groups had comparable CVP and vasoactive-inotropic scores (VIS), indicating that neither technique adversely affected hemodynamic support needs. This reinforces the safety profile of PIFB, which, unlike caudal blocks, does not require large volumes that risk rostral spread or hypotension. The absence of an increase in inotrope requirements in the PIFB group supports its hemodynamic neutrality.

No patient developed respiratory depression, pruritus, local anesthetic systemic toxicity, neurological deficit, hematoma, or block-related complications. The incidence of postoperative nausea and vomiting was similar between groups. No block failures were encountered.

Limitations

This single-center study with a relatively small sample size may limit the generalizability of the findings. Complete blinding of the anesthesiologist performing the block was not feasible because of procedural differences. Postoperative pain following pediatric cardiac surgery originates from multiple sources, including thoracic drain insertion; therefore, the addition of a rectus sheath block may have provided further analgesic benefit. Furthermore, intraoperative and postoperative fentanyl consumption were analyzed as a cumulative perioperative measure rather than as separate outcomes, limiting assessment of the individual opioid-sparing effects of PIFB. Because several hemodynamic variables demonstrated non-normal distributions, between-group comparisons were performed using the Mann–Whitney U test at individual time points. Although this approach is appropriate for non-parametric data, it does not model the group $\times$ time interaction. Future studies using generalized estimating equations or mixed-effects models would provide a more comprehensive longitudinal analysis.

Finally, long-term outcomes such as chronic postsurgical pain and neurodevelopmental effects were not evaluated.

Conclusion

Ultrasound-guided PIFB provided effective perioperative analgesia compared with caudal epidural block in children undergoing cardiac surgery via midline sternotomy, with lower postoperative pain scores,

reduced cumulative perioperative fentanyl consumption, fewer rescue analgesic requirements, and more stable intraoperative hemodynamics. Time to extubation was numerically shorter with PIFB, although the clinical significance of this difference remains uncertain. PIFB may therefore represent a useful component of multimodal opioid-sparing analgesia in pediatric cardiac surgery. Larger multicentre studies are warranted to confirm these findings.

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Research Registration Number:

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