NARRATIVE REVIEW ARTICLE

Regional Anesthesia With Fascial Plane Blocks for Pediatric Cardiac Surgery With Sternotomy: A Narrative Review

Gina C. Russell, MD,[1] and Lisa M. Einhorn, MD[2]

Undertreated pain in children who undergo sternotomy for cardiac surgery can lead to cardiopulmonary complications, the development of chronic pain, and long-term maladaptive stress response. Opioids have dose-dependent side effects that may interfere with postoperative recovery. With the increasing availability of ultrasound, regional anesthesia is often included in multimodal analgesic approaches. Fascial plane blocks targeting the intercostal nerves or ventral rami are of particular interest for patients requiring full heparinization for cardiopulmonary bypass as they avoid manipulation of neuraxial and noncompressible paravertebral spaces. This narrative review summarizes the literature on fascial plane blocks for pediatric patients undergoing cardiac surgery via midline sternotomy and may serve as a guide for clinicians. Both prospective and retrospective studies are reviewed, as are prior review articles. We describe individual fascial plane block techniques including the transversus thoracic muscle plane, pectointercostal fascial plane, serratus anterior plane, and erector spinae plane blocks and provide clinical considerations for each block. Additionally, we provide an analysis of individual studies stratified by anterior or posterior approach and block type. The majority of described studies examine single-shot blocks; the existing catheter literature, which includes erector spinae plane block catheters, is also included. Our findings suggest that fascial plane blocks decrease intraoperative and postoperative opioid use, pain scores, time to extubation, and length of stay in the intensive care unit and hospital. Notably, prospective studies in this field are small, typically fewer than 100 patients, and overall include a homogenous patient population, focusing primarily on patients with acyanotic congenital heart defects. Nonetheless, despite the limitations of individual studies, there is substantial evidence to support the use of regional anesthesia, particularly for patients in whom early extubation is planned. There is a need for large, prospective multi-center studies to evaluate the effectiveness and safety of specific single-shot block types, optimal local anesthetic dosing strategies compared to active comparators, and generalizability of results across institutions. Future studies should also consider evaluating the role of regional block catheters for continuous local anesthetic infusion and the inclusion of additional surgical populations, including neonates, patients with cyanotic lesions, and those with longer postoperative mechanical ventilation courses. (Anesth Analg 2026;142:507–517)

Pain is an important consideration in children after cardiac surgery, and poorly managed postoperative pain has clinically relevant short-term and long-term implications. In the immediate postoperative period, undertreated pain increases sympathetic nervous system activation and elevates the hormonal stress response, which may lead to arrhythmias, systemic hypertension, pulmonary hypertension, and other complications.[1,2] Ventilator dyssynchrony may lead to acid-base abnormalities of hemodynamic significance.[1] Long-term, pediatric patients undergoing sternotomy for cardiac surgery are at risk for chronic pain syndromes,[3] and negative postoperative pediatric intensive care unit (ICU) experiences have been associated with posttraumatic stress disorder.[1] Persistent poststernotomy pain is multifactorial and may arise from both nociceptive and neuropathic insults such as incision, rib retraction, tissue dissection, indwelling drains, visceral inflammation, and nerve injury.[4]

Postoperative analgesia has traditionally relied heavily on opioid strategies. While poor pain control negatively impacts postoperative outcomes, dose-dependent opioid-related side effects can also be deleterious to the recovery process. Specifically, opioid use can delay extubation due to respiratory suppression and hypoxia thereby predisposing patients to pulmonary complications, prolonged immobilization, suboptimal cardiopulmonary circulation, and increased ICU length of stay (LOS).[2,5,6] Opioids may also cause nausea, vomiting, and constipation,[7] and

From the [1]Department of Anesthesiology, Duke University School of Medicine, Durham, North Carolina; and [2]Department of Anesthesiology, Pediatric Division, Duke University School of Medicine, Durham, North Carolina.

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Address correspondence to Gina C. Russell, MD, Department of Anesthesiology, Duke University School of Medicine, 2301 Erwin Rd, Durham, NC 27710. Address e-mail to gina.russell@duke.edu.

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children exposed to 5 or more days of continuous opioids are at risk of developing dependency or withdrawal.[1] Thus, reducing the need for opioids while adequately managing poststernotomy pain is of critical importance to the recovery of children undergoing cardiac surgery.

Fascial plane blocks are a relatively new development in regional anesthesia that have gained popularity with the increased use of ultrasound imaging modalities and overall safety profile in the setting of anticogaulation.[6] The goal of this review is to describe techniques and relevant publications to guide clinicians interested in incorporating regional anesthesia into their perioperative care for pediatric cardiac surgery patients. Due to the risk of neuraxial-adjacent hematoma with heparinization, neuraxial and paravertebral blocks (PVBs) have become less popular; thus, this review focuses exclusively on fascial plane blocks in children.

METHODOLOGY

A literature search for this narrative review was conducted in MEDLINE via Ovid and PubMed in September 2024. Inclusion criteria were prospective and retrospective studies of regional anesthesia for children undergoing cardiac surgery via midline sternotomy. Exclusion criteria included neuraxial techniques, surgeon-administered blocks or wound infiltration, cardiac surgery via thoracotomy, case studies, letters to the editor, and publications in languages other than English. There was no date limit on the search period. Example MeSH terms included pediatric terms such as “child” and “infant”; procedure terms such as “sternotomy,” “congenital heart defects,” “atrial septal defects,” “ventricular septal defects,” and “canal defects”; regional anesthesia terms such as “nerve block” and “erector spinae plane blocks.” A qualified medical librarian assisted with the search. We identified 742 studies that were screened by title and abstract; 55 advanced to full article review, and 28 are discussed herein. The search strategy is depicted in Figure 1.

Chest Wall Fascial Plane Blocks: Advantages and Disadvantages

In this section, we describe the anatomical and technical considerations for fascial plane blocks stratified by anterior or posterior approach. A summary is provided in Table 1.

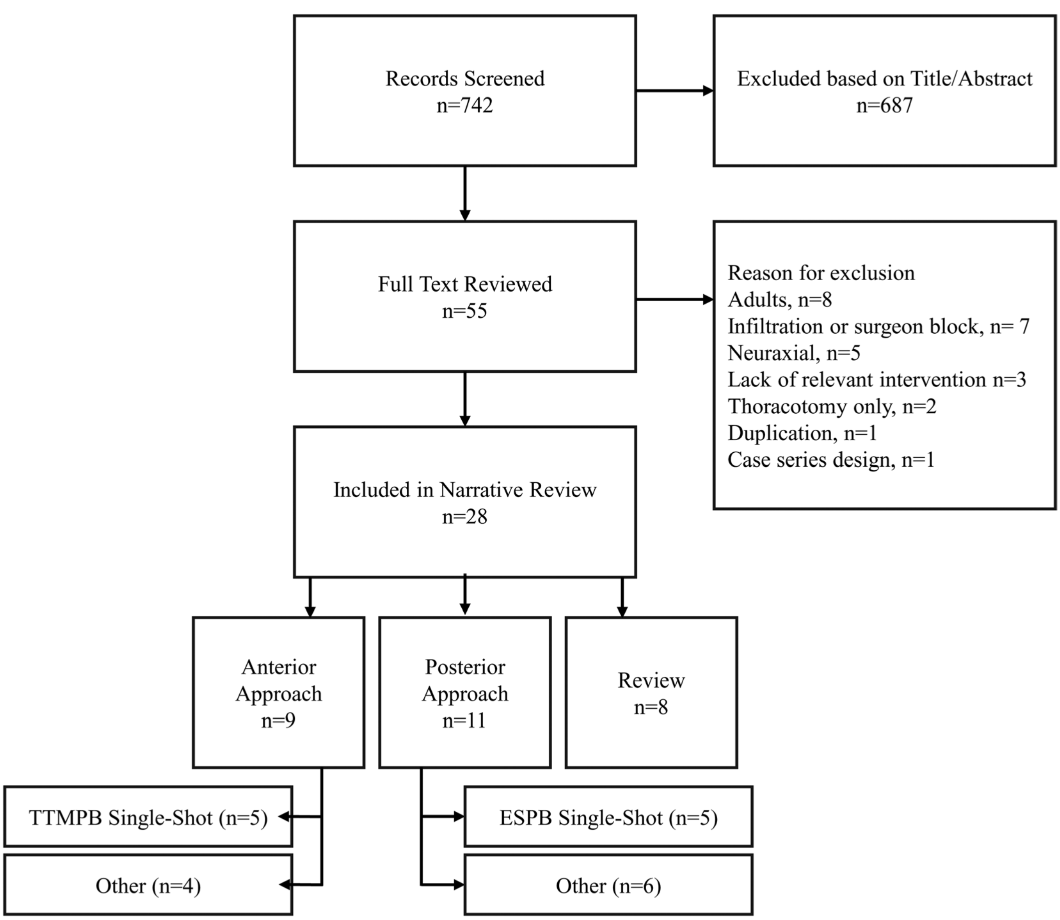

Figure 1. Flow diagram of search strategy. ESPB indicates erector spinae plane block; TTMPB, transversus thoracic muscle plane block.

Table 1. Summary of Chest Wall Blocks Stratified by Approach

Block	Targeted nerve(s)	Superficial/deep adjacent planes	Clinical considerations
Anterior approach			
Transversus thoracic muscle plane block	Anterior branches of the intercostal nerve	Intercostal muscles/Transversus thoracic muscle	Deep block; proximity of internal mammary artery
Pectointercostal fascial block	Anterior branches of the intercostal nerve	Pectoralis major muscle/Intercostal muscles	Superficial block; constrained local anesthetic spread
Deep serratus anterior plane block	Lateral cutaneous branches of the intercostal nerve	Serratus anterior muscle/Rib	Requires generous spread to reach anterior intercostal branches
Superficial serratus anterior plane block	Lateral cutaneous branches of the intercostal nerve	Latissimus dorsi/Serratus anterior muscle	
Intercostal nerve block	Anterior branches of the intercostal nerve	Internal intercostal muscle/Innermost intercostal muscle	Will not spread beyond rib interspace; multiple injections required
Posterior approach			
Erector spinae plane block	Ventral rami	Erector spinae muscle group/Vertebral transverse process	
Paravertebral block	Ventral rami	Superior costotransverse ligament/Pleura	Possible accidental neuraxial injection; noncompressible space
Midpoint transverse process block	Ventral rami	Posterior border of transverse process/superior costotransverse ligament	Relies on permeable superior costotransverse ligament for local anesthetic spread
Thoracic retrolaminar block	Ventral rami	Erector spinae muscle group/Lamina	Similar to paravertebral block, possible neuraxial injection
Multiple-injection costotransverse block	Ventral rami	Intertransverse ligament/Superior costotransverse ligament	

Anatomy. The sternum is innervated by the anterior cutaneous branches of the intercostal nerves associated with T2–T6.[8] The intercostal nerves originate from the ventral rami of thoracic spinal nerves and traverse the lateral thorax between the inner and innermost intercostal muscles.[8] The lateral cutaneous nerve branches off in the lateral thorax to provide sensory innervation to the anterolateral and posterolateral chest walls. The anterior cutaneous branch emerges parasternally to innervate the anterior chest wall. Chest wall anatomy is depicted in Figure 2.

Anterior Approach. Anterior blocks have the advantage of being performed while the patient is supine, consistent with the intraoperative patient positioning for cardiac surgery via median sternotomy. Blocks with an anterior approach can be safely performed either preoperatively or postoperatively after chest closure and drain placement.

Deep Parasternal Block/Transversus Thoracic Muscle Plane Block. The deep parasternal block, also called the transversus thoracic muscle plane block (TTMPB), was first described in 2015 by Ueshima et al[9] in a case study of a patient with severe cardiac dysfunction undergoing breast surgery. The TTMPB anesthetizes the anterior branches of the intercostal nerve from T2–T6 after injection of local anesthetic between the innermost intercostal muscle and the transversus thoracic muscle, which lies deep to the intercostal muscles.[8,10] An advantage of injection into this plane is the ability for local anesthetic to spread cranially and caudally for a multilevel sensory distribution.[8] Disadvantages include the vascularity of the targeted area which contains the internal mammary artery, the depth of the block with its proximity to the pleura and pericardium, and the poor visualization of the transversus thoracic muscle on ultrasound.[8,11]

Superficial Parasternal Block/Pectointercostal Fascial Block. The superficial parasternal block, also called the pectointercostal fascial block (PIFB), was initially described in 2014 for breast surgery[12] and targets the anterior cutaneous branches of the intercostal nerves.[11,13] Local anesthetic is deposited between the pectoralis major muscle and the intercostal muscles lateral to the sternum. The superficial nature of the block and the lack of vascular structures in the targeted area for infiltration add to the safety profile of the PIFB and make complications such as vascular injury, hematoma, pleural puncture, and pericardial puncture theoretically less likely. A disadvantage of the PIFB is a relatively more constrained spread of local anesthetic compared to the TTMPB,[8] thus requiring multiple sites of injectate depending on sternal length.

Serratus Anterior Plane Block. The serratus anterior plane block (SAPB) is generally thought to target the lateral cutaneous branches of the intercostal nerves. For the deep SAPB, local anesthetic is deposited between the rib and the serratus anterior muscle.[14] The superficial SAPB is performed with injectate placed between the serratus anterior and the latissimus dorsi muscles.[15] Though the targeted lateral cutaneous branches are not known to innervate the sternum, analgesia with sternotomy has been reported with both superficial and deep SAPB in pediatric patients,[14,15] which

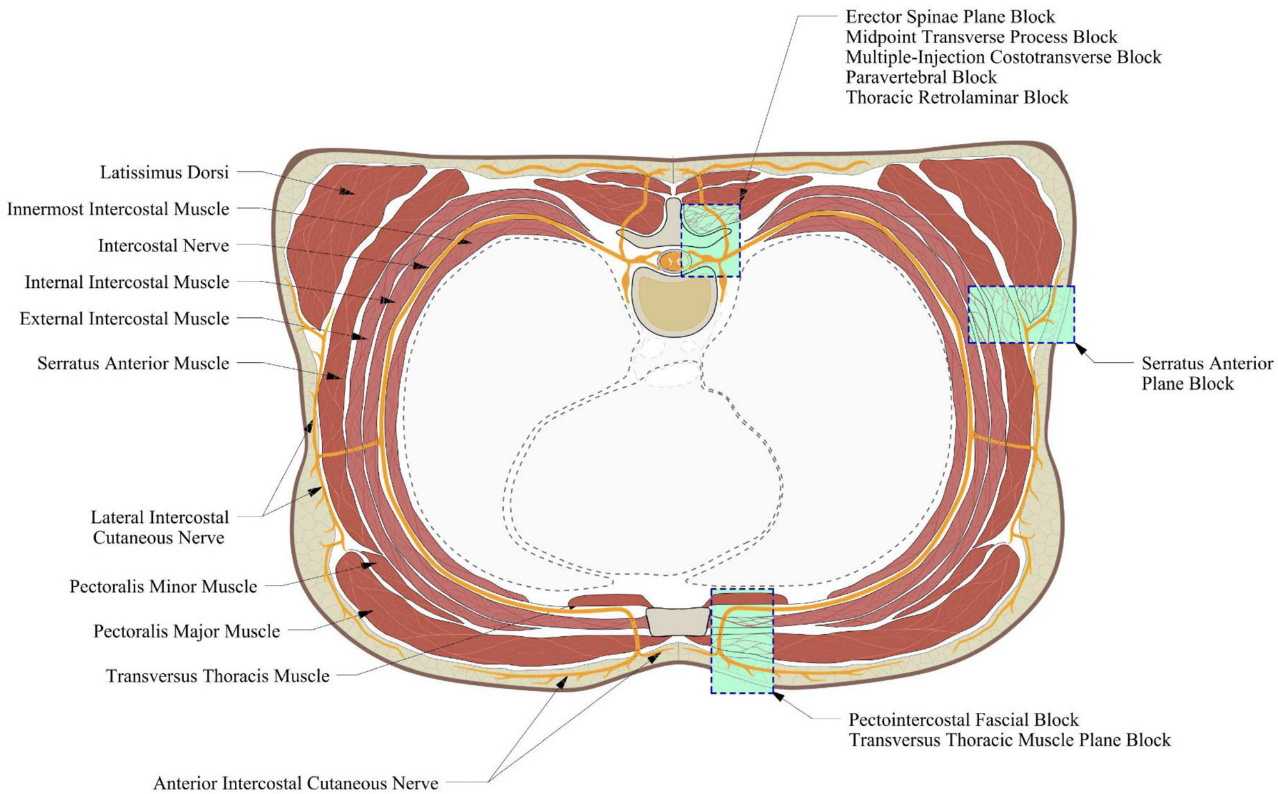

Figure 2. Cross-section of chest wall anatomy at approximately T7.

implies local anesthetic spread after this volume block. An advantage of the SAPB is its ability to be administered to a supine patient with relative distance from the sternotomy incision.

Posterior Approach. Blocks with a posterior approach target the intercostal nerves closest to their exit from spinal cord and are expected to have a wide sensory distribution that encompasses all distal branches. For pediatric patients, these blocks are generally administered postinduction in lateral decubitus position. The inability to administer posterior blocks postoperatively, when repositioning the patient would be impractical and potentially unsafe, is a disadvantage. Additionally, given the proximity to the epidural and intrathecal space, risk of hematoma development must be considered after full heparinization for cardiopulmonary bypass.

Erector Spinae Plane Block. The erector spinae plane block (ESPB), initially described by Forero et al,[16] targets the fascial plane that lies between the erector spinae muscle and the vertebral transverse process.[17] The main advantage of the ESPB is its ample local spread in the pediatric patient without violating the paravertebral space.[18] In a cadaver study of preterm neonates, undergoing ESPB, contrast material was also observed in the paravertebral and epidural spaces in addition to the anticipated dorsal and ventral rami.[18,19]

Paravertebral Block Variants. A number of anatomically superficial variations on the PVB have been described.[20] An advantage of these alternatives is the increased distance from pleura[20] and a theoretical avoidance of the noncompressible paravertebral space.[21]

Midpoint Transverse Process Block. Local anesthetic is injected at the midpoint between the transverse process and the pleura such that the paravertebral space is not directly violated by the block needle.[22]

Thoracic Retrolaminar Block. Local anesthetic is deposited when the block needle makes contact with the target vertebral lamina.[23] Injectate is thought to spread out of the retrolaminar space ventrally, into paravertebral and epidural spaces such that ventral and dorsal rami are anesthetized.[23]

Multiple-Injection Costotransverse Block. Similar to the MTP block, the multiple-injection costotransverse block (MICB) involves injection of local anesthetic near the paravertebral space. The block needle is advanced under ultrasound guidance to the inferior border of the superior rib anterior to the

Table 2. Summary of Studies of the Single-Shot Transversus Thoracic Muscle Plane Block

Author	Study type	N	Control	Summary of results (block intervention results versus control)
Abdelbaser and Mageed[25]	RCT	73	Sham block	- ↓ intraoperative*** and postoperative fentanyl (24 h)*** - ↓ postextubation pain scores at all time points* - ↑ time to rescue analgesia*** - ↓ time to extubation*** - ↓ ICU LOS***
Abdelbaser and Mageed[26]	Observational	198		1 (0.5%) pleural and pericardial puncture 1 (0.5%) subcutaneous hematoma
Cakmak and Isik[27]	Cohort	70	No block	- ↓ intraoperative*** and postoperative fentanyl (24 h)*** - ↓ postoperative pain scores at all time points*** - ↓ time to extubation***
Ohliger et al[28]	Cohort	37	No block	- ↓ intraoperative morphine** - ↓ average postoperative pain scores** - ↓ ICU LOS*
Zhang et al[29]	RCT	100	Sham block	- ↓ intraoperative** and postoperative fentanyl[a],** - ↓ postextubation pain scores (up to 24 h)** - ↓ time to extubation** - ↓ ICU** and hospital LOS**

Abbreviations: ICU, intensive care unit; LOS, length of stay; RCT, randomized controlled trial.
[a]No postoperative time period specified.
*P <.05; **P <.01; ***P <.001.

intertransverse ligament, just posterior to the superior costotransverse ligament.[24]

Chest Wall Fascial Plane Blocks: Current Evidence

In this section, we will review peer-reviewed studies of fascial plane blocks for pediatric patients undergoing cardiac surgery via midline sternotomy. Studies are presented by approach (anterior versus posterior) and further divided by block and then study type. Tables 2 and 3 present studies on the TTMPB and ESPB, respectively.

Frequently Reported Outcomes. The reviewed studies had similar primary and secondary outcomes. Opioid-related outcomes included weight-based intraoperative and postoperative opioid use. The perioperative opioid used varied (fentanyl/kg versus morphine/kg versus oral morphine equivalent [OME]/kg) as did the duration of measurement (12 vs 24 vs 48 or more hours). Postoperative or postextubation pain scores were other commonly reported outcomes; however, many authors reported pain scores in graphical format only, which made interpreting the magnitude of results challenging. ICU and hospital LOS were also frequently reported. Other measurements of postoperative recovery such as time to extubation, time to oral intake, and time to return of bowel function were included in some studies. Rarely, outcomes such as location of extubation (ie, operating room versus ICU), hemodynamic data (ie, heart rate and blood pressure), or serum local anesthetic concentrations were studied. Most studies stated that complications were recorded, but reported none,

Table 3. Summary of Studies of the Single-Shot Erector Spinae Plane Block

Author	Study type	N	Control	Summary of results (block intervention versus control)
Ali Gado et al[30]	RCT	98	No block	- ↓ intraoperative*** and postoperative morphine (24 h)*** - ↓ postoperative pain scores at various time points (p values not reported) - ↑ time to rescue analgesia*** - ↑ likelihood of extubation in the OR*
Cruz-Suarez et al[31]	Cohort	80	No block	- ↓ postoperative opioid (48 h)** - ↓ ICU* and hospital LOS**
Karacaer et al[32]	RCT	40	No block	- ↓ postoperative morphine (24 h)*
Kaushal et al[33]	RCT	80	No block	- ↓ postoperative fentanyl (12 h)*** - ↓ postextubation pain scores (up to 10 h)** - ↑ time to rescue analgesia*** - ↓ sedation scores*** - ↓ ICU LOS***
Somani et al[24]	RCT	84	No block	- ↓ postextubation pain scores (up to 10 h)* - ↓ intraoperative fentanyl** - ↓ use of fentanyl at incision*** - ↓ use of rescue opioid postoperatively*** - ↓ ICU LOS**

Abbreviations: ICU, intensive care unit; LOS, length of stay; OR, operating room; RCT, randomized controlled trial.
*P <.05; **P <.01; ***P <.001.

with the exception of one that focused exclusively on TTMPB complications.[26] A published commentary[34] discussed the challenges associated with outcome selection and reporting in this population, particularly when perioperative assessments (ie, postextubation pain scores) are not standardized between groups due to patient factors such as prolonged intubation.

Statistical Power. All randomized controlled trials (RCTs) included in this review described methodology for sample size calculation. Approaches varied between studies; sample size was calculated based on unpublished pilot studies, results of previously published peer-reviewed studies, or numerical benchmarks. All RCTs were adequately powered for primary outcomes.

ANTERIOR APPROACH

Deep Parasternal Block/ Transversus Thoracic Muscle Plane Block

RCTs. Zhang et al randomized 106 patients ages 6 to 60 months undergoing atrial septal defect (ASD) or ventricular septal defect (VSD) closure via sternotomy to receive an intervention consisting of bilateral, single-shot TTMPBs plus multimodal analgesia or the control of bilateral sham TTMPBs with saline plus multimodal analgesia.[29] Compared to controls, the intervention group had lower postextubation pain scores for 24 hours ($P < .01$), used less intraoperative and postoperative fentanyl, and had shorter time to extubation and LOS.

Abdelbaser and Mageed conducted an RCT to evaluate the effects of bilateral, single-shot TTMPBs after ASD, VSD or common AV canal repair.[25] This study of 73 patients ages 2 to 12 years demonstrated that postoperative fentanyl use was significantly lower for patients receiving the intervention compared to controls who underwent a sham block (9.9 vs 18.5 µg/kg, $P < .001$) as was intraoperative fentanyl use. Compared to controls, the intervention group had significantly lower postextubation pain scores for the first 24 hours ($P < .05$), shorter time to extubation and ICU LOS, and longer time to rescue analgesia.

Retrospective Studies. Cakmak and Isik examined outcomes after single-shot bilateral TTMPBs in a retrospective cohort study. Patients ages 2 months to 12 years undergoing repair of ASD, VSD, double outlet right ventricle (DORV), tetralogy of Fallot (TOF), and aortic stenosis (AS) received TTMPBs (n = 33) or standard multimodal analgesia (n = 37).[27] Compared to the control group, the intervention group received less intraoperative (7 vs 10 µg/kg, $P < .001$) and postoperative fentanyl in the first 24 hours (0 vs 2 µg/kg, $P < .001$). Postoperative pain scores and time to extubation were lower for the intervention group. There was no difference in ICU LOS.

In a small retrospective study, Ohliger et al evaluated perioperative outcomes for 37 patients ages 6 months to 14 years receiving bilateral single-shot TTMPBs (n = 16) compared to multimodal analgesia only (n = 21) for a variety of congenital heart surgeries.[28] Compared to the control group, the intervention group had lower intraoperative morphine use (0.4 vs 0.7 mg/kg, $P = .003$), lower postoperative pain scores, and shorter ICU LOS. There were no statistically significant differences in postoperative morphine use or time to oral intake between groups. In the 2 prior retrospective studies, bias may have impacted the study results as the anesthesiologists and ICU staff who assessed the patients' need for additional pain medications were not blinded.

Abdelbaser and Mageed evaluated the safety of bilateral, single-shot TTMPBs in a retrospective analysis of 198 pediatric patients (median age 19 months) undergoing a variety of cardiac surgeries via median sternotomy.[26] One patient experienced pleural and pericardial puncture due to loss of needle visualization; another patient sustained a self-limited hematoma unrelated to the internal mammary artery. Since most studies evaluating fascial plane blocks in this population are small, it is difficult to assess the true incidence of complications. This is the only study focused exclusively on identifying block-related complications and is the largest study included in this review. The low overall complication rate (1%) suggests a favorable safety profile for the TTMPB, though the nature of the complication (pleural and pericardial puncture) is an important reminder of the proximity of this deep anterior block to vital structures.

Superficial Parasternal Block/Pectointercostal Fascial Block

RCT. Zhang et al randomized 51 patients to receive bilateral, single-shot PIFB before incision, and 50 patients to a control group that received saline sham block.[35] The patients ranged from 2 to 6 years old, and underwent either ASD or VSD repair. Compared to controls, the intervention group had significantly lower postextubation pain scores at rest and while coughing for all time points within the first 24 hours (all $P < .05$). The intervention group also demonstrated shorter time to extubation, time to first bowel movement, and LOS, as well as lower intraoperative and postoperative fentanyl use, though no time period was specified for measurement of postoperative fentanyl use.

Randomized Comparison Trial. Elbardan et al published a randomized comparison trial of 60 children, ages 2 to 12 years, who underwent cardiac surgery for repair of ASD, VSD, or AV canal defect and were randomized to receive either PIFB (n = 30) or TTMPB (n = 30) after induction of anesthesia.[36] There was no control group. The TTMPB group used significantly less intraoperative (2 [2–2] vs 2 [2–4] mcg/kg, $P = .03$) and postoperative fentanyl (12 [10–12] vs 15 [15–16] mcg/kg, $P < .001$) compared to the PIFB group. This is the only study comparing commonly used fascial plane blocks. Results suggest that TTMPB may be more effective than PIFB; however, the magnitude of differences was not clinically significant.

Retrospective Study. Einhorn et al evaluated the effects of bilateral, single-shot PIFB and unilateral, single-shot rectus sheath block ipsilateral to the chest tube (n = 23) with a control group (n = 66) receiving surgeon-infiltrated local anesthetic at both sites.[11] Patients were ages 3 months to 16 years and underwent ASD or VSD repair. The intervention group used less opioid than the control group for the first 12 hours postoperatively (0.3 vs 0.6 OME/kg, $P < .001$). Postoperative pain scores were significantly lower for the intervention group at 12 hours compared to the control group, as was hospital LOS. There was no difference in opioid use or pain scores beyond 12 hours or time under general anesthesia. This study is unique for including an intervention to address chest tube site pain; other studies focus exclusively on sternotomy pain and do not describe the source of pain being addressed with postoperative analgesics.[37]

Serratus Anterior Plane Block

RCT. He et al randomized 60 patients ages 1 month to 6 years to receive single-shot, bilateral SAPB (n = 20), intercostal nerve block (ICNB) (n = 20), or no block (n = 20) with multimodal analgesia.[38] Compared to the control group, the groups receiving SABP and ICNB had significantly less morphine use (mcg/kg) in the first 24 hours (control 359 vs SABP 169, $P < .001$, control versus ICNB 170, $P < .001$). The difference between SABP and ICNB was not significant. There was no difference in time to extubation, LOS, or postextubation pain scores. Plasma concentration of ropivacaine was measured at various time points and similar for both blocks with large intersubject variability.

POSTERIOR APPROACH

Erector Spinae Plane Block Single-Shots

RCTs. Kaushal et al randomized 85 pediatric patients (mean age 29 months) undergoing ASD or VSD repair to receive bilateral single-shot ESPBs or standard multimodal analgesia.[33] Compared to the control group, patients who received ESPBs had lower postextubation pain scores for the first 10 hours (3.9 vs 4.4 at hour 10, $P = .007$); however, the difference in pain intensity became less clinically meaningful over time. In addition, the block group had less postoperative fentanyl, lower sedation scores, shorter ICU LOS, and longer time to rescue analgesia.[33] There were no differences in intraoperative fentanyl use or time to extubation between groups.

Karacaer also studied the effect of bilateral, single-shot ESPB in 40 pediatric patients ages 2–10 years for ASD closure, VSD closure, or aortic membrane excision.[32] Patients in the intervention group had lower morphine use in the first 24 hours compared with the control group that received the study institution's standard multimodal analgesia and no block (0.3 vs 0.8 mg/kg, $P = .04$). No differences in pain scores, sedation, time to extubation, ICU and hospital LOS, or PONV were identified.

Ali Gado et al compared single-shot ESPBs with a control group receiving no blocks for 98 pediatric patients ages 6 months to 7 years undergoing acyanotic cardiac surgery.[30] Compared to the control group, intraoperative fentanyl use was less for the intervention group (4.3 vs 6.7 μg/kg, $P < .001$), as was postoperative use. Time to rescue analgesia was longer, operating room extubation was more likely, and postoperative pain scores were lower for the intervention group compared to the control group.

Somani et al compared bilateral single-shot ESPBs, the MICB, and a control group receiving no regional anesthesia for patients ages 8 months to 10 years undergoing ASD, VSD or combined closure.[24] Patients in both the ESPB (n = 28) and MICB (n = 28) groups had lower postextubation pain scores compared to the control group (n = 28) for the first 10 hours (at hour 10, ESPB 1.3 vs control 1.8, $P = .03$; MICB 1.4 vs control, $P = .045$). Patients in both intervention arms required less intraoperative fentanyl and were less likely to receive fentanyl on incision or rescue opioid in the ICU compared to the control group. Neither block was associated with lower postoperative opioid use compared to controls. Block patients had shorter ICU LOS; hospital LOS was equivalent between groups.

Retrospective Studies. Cruz-Suarez et al analyzed 80 patients (median age of 9.5 months) undergoing cardiac surgery (Risk Adjustment for Congenital Heart Surgery, RACHS, levels 1–3) with midline sternotomy or a combined approach in a retrospective cohort study.[31] The intervention group received a bilateral single-shot ESPB combined with multimodal analgesia, while the control group received conventional multimodal analgesia and no block. The intervention group had shorter hospital and ICU LOS compared to the control group (6.5 vs 10.5 days, $P = .007$, and 4 vs 6 days, $P = .01$, respectively), and lower morphine use for the first 48 hours postoperatively.

There were no other secondary outcome differences between groups.

Erector Spinae Plane Block Catheters

RCT. Macaire et al enrolled 54 pediatric patients (mean age 25 months) undergoing various cardiac surgeries to receive bilateral, single-shot ESPB and subsequent catheter placement.[19] Those randomized to the catheter intervention began a programmed, intermittent bolus regimen with ropivacaine for 48h postoperatively; the control group received the same regimen with infused saline. The intervention group had significantly less morphine use for 48 hours postoperatively (120 vs 512 µg/kg, $P = .03$), decreased need for rescue opioid in the ICU, and lower pain scores at various postoperative intervals compared to the control group. Instances of PONV were lower in the intervention group compared to the control group but no other differences in secondary outcomes were observed. Plasma ropivacaine levels at various time points were measured and remained below the accepted safe level of 1.5mcg/mL. This study used 2 different pain scales which had discordant results at times, highlighting the challenges of pediatric pain assessment.

Retrospective Studies. Roy et al completed a retrospective cohort study of bilateral ESPB catheters for patients ages 5 to 17 years (n = 30) undergoing repair of ASD, VSD or an anomalous coronary artery.[39] Ten patients received the intervention of standard multimodal analgesia plus postoperative ESPB, followed by catheter placement and ropivacaine infusion; controls received the study institution's standard multimodal analgesia. Ropivacaine infiltration at the sternal wound and drain sites was administered for 85% of control patients. Postoperative opioid use was significantly lower for patients receiving bilateral ESPB catheters compared to the control group (0.8 vs 1.1 OME/kg, $P = .04$). The median time for catheter placement was 16.0 minutes.

After the pilot study discussed above,[39] Roy et al completed a second, larger cohort study[40] evaluating bilateral ESPB catheters. The 40 intervention and 78 control patients ages 2 to 17 years underwent a heterogenous group of surgical procedures. Patients in both groups received ropivacaine wound infiltration (89% of controls vs 48% of catheter patients, $P < .001$). Patients receiving the ESPB catheter intervention used significantly less opioid in the first 24 hours postoperatively compared to the controls (0.6 vs 0.8 OME/kg, $P = .02$). There were no differences in pain scores, likelihood of early extubation, time to mobilization, PONV or LOS between groups. Patients receiving the intervention spent a median of 31 minutes more in the operating room compared to controls. The use of local anesthetic wound infiltration in both the intervention and control group makes these results difficult to interpret and may not reflect typical practice patterns given maximum local anesthetic dosing concerns. This study is unique for assessing the median cost increase associated with a catheter intervention ($6909).

Midpoint Transverse Process Block

There are 2 RCTs that evaluate the newly described midpoint transverse process (MTP) block. Abdelbaser et al randomized patients ages 2 to 10 years undergoing repair of ASD, VSD and AV canal defects to receive the ultrasound-guided, single-shot, bilateral block (n = 23) or standard multimodal analgesia (n = 23).[41] Fentanyl use in the first 24 hours was significantly lower in the group receiving the block compared to the control (4.4 vs 6.0 µg/kg, $P < .001$). Abourezk et al found the MTP was noninferior to PVB in a RCT that randomized 58 children ages 2 to 12 years undergoing repair of ASD, VSD or AV canal defects to receive either block.[42] Fentanyl use in the first 24 hours postoperatively was not significantly different between the groups.

Thoracic Retrolaminar Block

The thoracic retrolaminar block (TRLB) was examined by Abdelbaser et al in an RCT involving patients 2 to 8 years undergoing repair of ASD, VSD, or AV canal defects who were randomized to receive the bilateral, single-shot, ultrasound-guided block (n = 29) or sham block with saline (n = 29).[23] The primary outcome, fentanyl use in the first 24 hours postextubation, was found to be significantly lower in the intervention group compared to the control group (6.9 vs 16.6 µg/kg, $P < .001$).

The previously described PVB variants (ie, MTP, TRLB, MICB) are more superficial than the PVB and still provide anesthesia to the ventral and dorsal rami as injectate diffuses. However, there is currently no evidence of improved safety with these variants compared to the PVB. Given other blocks provide similar efficacy and are performed at a greater distance from the neuraxial space, the utility of PVB variants is currently unclear.

Review Articles

Schmedt et al[43] recently published a systematic review and meta-analysis of RCTs of peripheral regional anesthesia for both adults and children[25,29,33] undergoing cardiac surgery; descriptive data from the pediatric trials is shown in a supplementary table rather than a meta-analysis due to insufficient data. Greene et al recently published a systematic review and meta-analysis of ESPB for midline sternotomy for adults and children.[44] The pediatric[30,32,33] and adult studies were analyzed together. Lombardi et al[45] recently conducted a systematic review and meta-analysis of ESPB for midline sternotomy in pediatric[24,30–33] patients undergoing cardiac surgery (n = 384). The authors reported significantly less intraoperative opioid use and shorter ICU LOS. Postoperative opioid use and pain scores could not be assessed due to inconsistent or incomplete data.[45] Cui et al conducted a systemic review and meta-analysis of single-shot TTMPB for pediatric cardiac surgery via sternotomy and thoracotomy in 2023 (n = 601)[46] which included RCTs[25,29] and retrospective[27] studies. Pooled outcomes from the included RCTs showed statistically significantly lower pains scores, less intraoperative and postoperative opioid use, shorter time to extubation, and shorter ICU LOS.

Yamamoto and Schindler reviewed the effect of regional anesthesia on enhanced recovery after surgery (ERAS) for the pediatric cardiac population in 2023.[8] Fascial plane anatomy, blocks and key findings from prior studies are reviewed. Hong et al published a narrative review of fascial plane block RCTs for adults and children undergoing cardiac surgery in 2022.[47] Raj published an educational review in 2019 detailing regional anesthesia for pediatric patients undergoing bypass via sternotomy which included technical guidance and ultrasound images.[6] Pollak and Serraf reviewed postoperative pain management for pediatric cardiac surgery in 2018, however focused on neuraxial regional techniques only.[1] They describe physiologic implications of pain in this population, measurement tools, and different components of multimodal analgesia.[1]

DISCUSSION AND FUTURE DIRECTIONS

Numerous prospective and retrospective studies have identified beneficial outcomes associated with regional anesthesia use for pediatric cardiac surgery including lower pain scores, less intraoperative and postoperative opioid use, shorter time to extubation, and shorter LOS in the context of a multimodal analgesic plan. These findings are particularly relevant in those patients eligible for early extubation and enhanced recovery protocols.

We recognize that there are inherent limitations to the studies presented in this review. There are notable issues with study design related to the definition and assessment of outcomes, blinding, and control group selection. Most studies were small (<100 patients), single-center trials designed with a sham placebo or unblocked control group. Surgeon-administered local anesthetic infiltration is a frequent alternative to anesthesiologist-administered nerve blocks. It is possible that between group differences would have failed to achieve significance had this active comparator served as a control. Likewise, while most studies showed statistically lower pain scores favoring the block groups, fewer studies defined or showed clinically meaningful differences in pain intensity.[48] Furthermore, all but one publication[11] failed to address pain associated with indwelling pleural and mediastinal drains. Many important and clinically relevant core domains for pediatric pain clinical trials as defined by PEDIMMPACT[49] including physical and functional recovery, sleep, global satisfaction, and economic factors were not examined. Finally, results may not be generalizable due to the narrow populations studied. Nonetheless, despite these acknowledged limitations, based on the analgesic and opioid-sparing benefits and lack of major complications associated with block placement, these authors believe that regional anesthesia should be considered as part of a multimodal analgesic regimen for all pediatric patients undergoing sternotomy.

Future research is needed to determine the optimal block, local anesthetic, dosage, and timing of injection. Preincisional regional anesthesia may decrease sympathetic stimulation, reduce intraoperative opioid use, and be easier to administer before surgical interruption of anatomic fascial planes. Postoperative blocks, however, offer longer postoperative analgesia, which is particularly relevant for the first night after surgery when opioid use is the highest.[50] Children's anatomical development may lead to differences in the spread of local anesthetic across tissue planes compared to adults, and additional research is needed to assess the benefit of catheters compared to ultrasound-guided, single-shot blocks. Investigations on the potential benefits of regional anesthesia in additional surgical subpopulations, specifically neonates, is needed. Finally, larger studies should be designed with active comparators to determine the strength of the analgesic effect of specific fascial planes blocks and the potential benefit of one technique over another.

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