Thoracic Wall Fascial Plane Blocks for Pediatric Cardiac Surgery with Sternotomy

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Abstract

Aim: In paediatric patients undergoing sternotomy for cardiac surgery, inadequate pain management has been demonstrated to result in cardiopulmonary complications, the development of chronic pain, and prolonged stress responses. Opioids, which are frequently utilised for the purpose of analgesia in these patients, have been observed to induce dose-dependent adverse effects that have the potential to influence postoperative recovery.

Methods: The increased utilisation of ultrasound in recent years has led to the integration of regional anaesthesia into multimodal analgesic approaches and its incorporation into Enhanced Recovery After Surgery (ERAS) protocols following cardiac surgery. Fascial plane blocks target intercostal nerves and ventral branches at multiple levels. Moreover, as they do not cause damage to the neuroaxial and paravertebral spaces during the procedure, they are a suitable option for postoperative analgesia in patients requiring full heparinisation for cardiopulmonary bypass.

Conclusions: This review synthesises the extant literature on thoracic fascial plane blocks for paediatric patients undergoing cardiac surgery via median sternotomy, with the objective of providing a practical guide for clinicians.

Keywords: *Pediatric cardiac surgery; fascial plane blocks; postoperative analgesia*

1. Introduction

Paediatric cardiac surgery performed through median sternotomy or thoracotomy is associated with moderate- to- severe postoperative pain[1]. In such cases, insufficient management of acute postoperative pain can lead to deleterious short-term and long-term adverse effects[2,3]. Inadequate pain management in the early postoperative period has been demonstrated to result in a number of complications via activation of the sympathetic nervous system and hormonal stress response. These include haemodynamic reactions (e.g. arrhythmias, systemic and/or pulmonary hypertension), postoperative pulmonary complications, prolonged intubation, and prolonged intensive care unit and hospital stays[4,5]. In the long term, a number of nociceptive and neuropathic factors, including surgical incision, rib retraction, nerve damage, tissue dissection and inflammation, and indwelling drains can contribute to persistent poststernotomy pain in paediatric patients undergoing cardiac surgery[6].

Until recently, the predominant approach to postoperative analgesia involved the use of opioids. However, inadequate pain management and dose-dependent opioid-related adverse effects are commonly observed. Opioid use has been demonstrated to result in a range of adverse outcomes, including pulmonary complications and prolonged intubation due to respiratory depression and hypoxia and prolonged intensive care unit stay. Furthermore, these effects can lead to haemodynamic and gastrointestinal complications, such as hypotension, nausea, vomiting and constipation[5,7,8]. Enhanced Recovery After Surgery (ERAS) protocols for paediatric cardiac procedures recommend the optimisation of analgesia with minimal side effects for the management of postoperative pain in these patients[9]. Consequently, in order to reduce the use of opioids, enhance perioperative outcomes and prevent complications, multimodal analgesia (MMA) techniques have been frequently employed in recent years[10]. For this purpose, a variety of regional anaesthesia (RA) techniques, including neuraxial approaches and fascial plane blocks, have been proposed for paediatric patients undergoing cardiac surgery[11].

Although neuroaxial interventions such as caudal, epidural, and spinal blocks have been shown to be useful as part of postoperative MMA in paediatric cardiac surgery, their use is not widespread due to potential concerns about epidural haematoma during full heparinisation[12,13]. Facial plane blocks are relatively new and less invasive techniques in regional anaesthesia and based on the principle that the eposistion of local anesthetic into an anatomic area will spread between tissue planes, usually between muscles and/or ligaments, thereby blocking the nerves in that area. They have gained popularity with the increased use of ultrasound imaging techniques and their overall safety profile in an anticoagulation setting[14].6 The utilisation of these blocks in cardiac surgery is increasing, primarily due to their relative safety and simplicity of application, in addition to their proximity to the surgical site[15]. A meta-analysis of 33 studies on adult and paediatric patients reported that postoperative pain intensity was significantly reduced in adult patients administered

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peripheral RA compared to control groups. However, due to the limited number of studies conducted in children, meta-analysis was not performed[16]. A meta-analysis of twenty-four studies in children undergoing cardiac surgery found that all regional anaesthetic techniques used in the studies reduced postoperative opioid consumption within the first twenty-four hours and prolonged the time to first rescue analgesic. However, this meta-analysis noted that indirect comparisons were limited due to the heterogeneity of the studies, and direct comparisons were required[17].

Consequently, there are uncertainties regarding the mechanism of action, pharmacokinetics, volume, and concentration of local anaesthetics (LA) used in paediatric patients[11,18,19]. The objective of this review is to provide a comprehensive overview of the current state of knowledge and clinical application of RA in paediatric patients undergoing cardiac surgery. The review aims to serve as a guide for clinicians by synthesising the findings of clinical studies that have investigated the effectiveness of these blocks.

2. Fascial Plane Blocks

The sternum is innervated by branches of the intercostal nerves, particularly the anterior cutaneous branches of the intercostal nerves (T2-T6). These nerves provide somatic sensory fibres that can mediate pain resulting from trauma (e.g., sternal fracture) or surgical incisions[20]. The lateral cutaneous nerve branches in the lateral thorax provide sensory innervation to the anterolateral and posterolateral chest walls. The anterior cutaneous branch originates from the parasternal region, innervating the anterior chest wall[21].

Fascial nerve blocks, which are increasingly utilised in conjunction with systemic analgesics in cardiac surgery, are performed via an anterior or posterior thoracic approach (Table 1). Anterior blocks are advantageous in that they can be administered for postoperative analgesia following median sternotomy, either pre- or postoperatively, with the patient in a supine position[21].

Table 1

Thoracic Wall fascial plane blocks, categorised by the approach used

BLOCK	Anatomical Plan / Injection Level	Affected Area / Nerves	Advantages	Disadvantages
ANTERIOR APPROACH				
Parasternal Intercostal Plane Block (Superficial)	Between the pectoralis major and the external intercostal muscle (or internal intercostal membrane), close to the sternum	Anterior cutaneous branches (T2–T6)	Simple application, effective for sternotomy analgesia	Analgesia only in the medial region; limited dermatomal spread
Parasternal Intercostal Plane Block (Deep)	Between the internal intercostal and transverse thoracic muscles	Anterior cutaneous branches (T2–T6)	Deeper and stronger block, effective for sternotomy analgesia	Deep application; the risk of pneumothorax is slightly higher
Interpectoral Plane Block (PECS I)	Between the pectoralis major and pectoralis minor	Medial and lateral pectoral nerves	Easy ultrasonic identification; sufficient in pectoral muscle surgeries	Insufficient on its own
Pectoserratus Plane Block (PECS II)	Between the pectoralis minor and serratus anterior (at the level of ribs 3–5)	Lateral cutaneous intercostal branches, long thoracic, thoracodorsal nerve	wide front chest coverage	Near deep structures; not long-acting; risk of intramuscular spread
Serratus Anterior Plane Block (Superficial/ Deep)	Above or below the serratus anterior (at the mid-axillary line between ribs 4 and 6).	Lateral cutaneous branches (T2–T6)	Effective after thoracotomy; safe	May be insufficient for posterior pain; single dermatome block is limited
POSTERIOR APPROACH				
Erector Spinae Plane Block	Under the erector spinae muscle, on the transverse process	Dorsal and ventral branches; paravertebral spread	Easy and safe; multiple dermatome analgesia; wide range of applications	Effect variability; paravertebral spread is not always consistent
Midpoint Transverse Process Block	Between the erector spinae and the transverse process, slightly deeper than the ESPB	Dorsal and ventral branches	More predictable spread compared to ESPB; alternative to paravertebral block	The application is more in-depth; technically more challenging.
Thoracic Retrolaminar Block	Between the erector spinae muscle and the lamina	Dorsal branches ± ventral branches	Safe, away from the epidural; effective for posterior thoracic pain	Limited spread to the ventral branches; weak anterior thoracic analgesia
Multiple-Injection Costotransverse Block	On the costotransverse ligament, at several levels	Ventral branches, sympathetic chain	Strong multi-dermatome analgesia at the paravertebral level; stable spread	Multiple needle insertions; time-consuming; technical knowledge

The transverse thoracic muscle plane block (TTPB) and pectointercostal fascial block (PIFB), administered via the anterior approach, anaesthetise the anterior (parasternal) chest wall. The serratus anterior plane block (SAPB) via the anterior approach anaesthetises the lateral chest wall[22]. Erector spinae plane block (ESPB), midpoint transverse process block (MTPB), thoracic retrolaminar block (TRLB) and multiple-injection costotransverse block (MICB) are administered via posterior thoracic approach[23-26]. Posterior approach blocks target the intercostal nerves closest to their origin from the spinal cord and block a broad sensory distribution encompassing all distal branches. In paediatric patients, these blocks are generally performed in the lateral decubitus position after induction and are not suitable if the patient's position cannot be changed. Furthermore, the risk of hematoma formation after complete heparinisation for cardiopulmonary bypass must be considered due to its proximity to the epidural and intrathecal spaces[21].

3. Anterior Thoracic Fascial Plane Blocks

3.1. Superficial and Deep Parasternal Intercostal Plane Blocks

Superficial and deep parasternal intercostal blocks (A-PIP and D-PIP), previously known as pectointercostal fascia and transversus thoracic plane blocks, respectively, block the anterior cutaneous branches of the intercostal nerves from approximately the T2 to T6 levels. Therefore, these blocks are utilised for midline chest incisions, encompassing complete and partial sternotomies, and anterior thoracotomies[27,28]. In the context of a superficial PIP block, the LA is injected between the pectoralis major muscle and the internal intercostal muscle, and/or the external intercostal membrane. When performing a deep PIP block, the LA is injected between the transversus thoracic muscle and the internal intercostal muscle[28]. A meta-analysis was conducted to compare the analgesic efficacy of S-PIP and D-PIP blocks. The analysis found no significant difference between the two methods in terms of 24-hour postoperative morphine consumption, pain scores, PONV incidence, time to rescue analgesics, extubation time, or ICU LOS[29]. However, in another study comparing the two block methods, a greater number of pneumothoraces were observed in the DPIP group[30]. Although complications are minimized by performing fascial plane blocks under ultrasound guidance, it is imperative to exercise the utmost caution when undertaking D-PIP blocks in paediatric patients. This is due to the potential for pneumothorax and the risk of injury to the internal thoracic artery[31].

3.2. Interpectoral Plane and Pectoserratus Plane Blocks

The interpectoral plane block (IPPB, previously termed PECS-I) is administered via LA injection into the interfascial plane between the pectoralis major and pectoralis minor muscles, with ultrasound guidance. In the IPPB + pectoserratus plane block (PSPB, previously called PECS-II), LA is injected into two separate interfascial planes: the first between the pectoralis major and minor muscles, and the second between the pectoralis minor and serratus anterior muscles[32,33]. The IPPB targets the medial and lateral pectoral nerves, while the PSPB additionally blocks the thoracodorsal nerve, the long thoracic nerve, the intercostobrachial nerve, and the lateral cutaneous branches of the T2-6 intercostal nerves[34]. IPPB and PSPB can be administered in a single dose or as a continuous infusion. In a study conducted by Gaweda et al.[35], 30 adult patients who underwent mitral and/or tricuspid valve repair via minithoracotomy were divided into two groups; one group received only ESPB, while the other received IPPB + PSPB + ESPB. In this study, postoperative opioid consumption was found to be lower in patients in the IPPB + PSPB + ESPB group than in those in the ESPB group. Despite the extensive utilisation of the IPP block for postoperative analgesia in breast surgery, studies in cardiac surgery remain sparse and are predominantly focused on adult patients. Consequently, these blocks should be used with caution in paediatric patients.

3.3. Serratus Anterior Plane Block

The serratus anterior plane block (SAPB) is performed in the axillary region, at the level of the fourth or fifth rib, more laterally and posteriorly than the interpectoral block. For SAPB the LA is injected between the rib and the serratus anterior muscle, while for superficial SAPB, it is injected between the serratus anterior and latissimus dorsi muscles[36,37]. The affected nerves by the injection depend on whether it is performed superficially or deeply: Deep SAPB blocks the lateral cutaneous branches of the intercostal nerves, while superficial SAPB blocks the long thoracic and thoracodorsal nerves, as well as the lateral cutaneous branch of the intercostal nerve[38]. The administration of SAPB provides analgesia to the anterior, lateral, and posterior chest walls, extending to levels T2–9. SAPB can be administered in a single dose or as a continuous infusion.

A study was conducted on children undergoing video-assisted thoracoscopic surgery to compare the postoperative analgesic efficacy of SAPB and thoracic paravertebral block (PVB)[39]. It was reported that the mean morphine consumption and pain scores during the first 24 hours postoperatively were similar between the groups, and that SAPB provided effective and safe pain control similar to thoracic PVB. In a study conducted by Kaushal et al.[40], the efficacy of SAPB, IPP + PSP block, and intercostal nerve block (ICNB) for the management of post-thoracotomy pain in paediatric patients undergoing cardiac surgery via thoracotomy was compared. While no difference was found in pain scores in the early postoperative period, pain scores were significantly lower in the SAPB and IPPB + PSPB groups compared to the ICNB group in the late period. Moreover, postoperative opioid consumption was reported to be lower in the SAPB and IPPB + PSPB groups compared to the ICNB group.

It is unknown whether the lateral cutaneous nerve branches blocked by SAPB are involved in sternal innervation, but case reports have reported analgesia with SAPB in pediatric patients undergoing median sternotomy[36,37]. This effect is thought to be due to LA spread due to volume effect.

4. Posterior Thoracic Plane Blocks

4.1. Erector Spinae Plane Block

The erector spinae plane block (ESPB) is performed by injecting LA into the fascial plane between the erector spinae muscle and the vertebral transverse process[41]. The precise mechanism of action of ESPB remains a subject of debate in the literature. However, the most probable mechanism is the spread of the administered LA in a craniocaudal direction and into the paravertebral space, and, less frequently, into the dorsal rami and epidural space[42]. Consequently, the blocking of the dorsal and ventral branches of the spinal nerves and sympathetic ganglia results in the production of both somatic and visceral sensory blockade. When applied bilaterally, the ESPB has been shown to provide effective analgesia by covering the entirety of the thorax, particularly in the T2-7 regions. In a cadaver study of premature neonates undergoing ESPB, contrast material spread was reported in the paravertebral and epidural spaces in addition to the expected dorsal and ventral rami[43]. In comparison with alternative regional techniques, such as paravertebral or neuraxial blocks, ESPB is a less complicated method to administer and, due to its more superficial nature, is not contraindicated in patients receiving anticoagulant therapy. Consequently, it has been frequently preferred for postoperative analgesia in cardiac surgery patients in recent years[21,34]. ESPB can be administered in a single dose or as a continuous infusion.

Numerous studies have demonstrated the efficacy of the ESPB for paediatric cardiac surgery[44-47]. A meta-analysis of five studies and 384 patients was conducted to compare the postoperative effects of bilateral ESPB with IV analgesia in paediatric patients undergoing cardiac surgery through a midline sternotomy. This meta-analysis found lower intraoperative fentanyl consumption and shorter intensive care unit stay in children undergoing ESPB. However, no differences were observed in hospital length of stay, time to first analgesia rescue, extubation time, or frequency of vomiting[48]. A further meta-analysis, encompassing 16 studies and 1,110 patients, was performed to evaluate the effectiveness of ESPB in paediatric cardiac surgery. This analysis found no difference in 24-hour opioid consumption between children who received ESPB and those who did not. However, 48-hour opioid consumption was significantly lower in the ESPB group than in the control group. Furthermore, the duration of ventilation, time to first mobilisation, and length of stay in the intensive care unit and hospital were also found to be reduced in the ESPB group[49]. Recent studies and meta-analyses highlight that ESPB makes an effective contribution to the current multimodal analgesia strategy by reducing opioid consumption, pain scores, and length of stay in the intensive care unit and hospital in paediatric patients undergoing cardiac surgery.

4.2. Midpoint Transverse Process Block

The mid-point transverse process block (MTPB) has been identified as a novel variant of the thoracic paravertebral block (TPVB). The injection of the local anaesthetic is to be administered at the midpoint between the transverse process and the pleura, thus ensuring that the paravertebral space is not compromised by the insertion of the block needle[25]. LA spreads in the paravertebral space, thereby blocking the spinal nerve roots of the ventral and dorsal branches. Concurrently, it also spreads laterally to block the lateral cutaneous branch of the intercostal nerve[25].

Abourezk et al.[50] compared TPVB and MTPB in paediatric patients undergoing midline sternotomy. The objective of this study was to assess the efficacy of these techniques in reducing the intraoperative haemodynamic stress reaction to noxious surgical stimuli and postoperative analgesia. It has been demonstrated that MTPB is non-inferior to TPVB in reducing intraoperative haemodynamic stress response and postoperative opioid consumption. It is also technically easier and faster to perform.

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4.3. Thoracic Retrolaminar Block

Thoracic retrolaminar block (TRLB), as with MTPB, is a recently developed regional analgesic technique employed as an alternative to TPVB as a component of postoperative multimodal analgesia[51]. The injection of LA between the posterior surface of the thoracic vertebral lamina and the overlying paraspinal muscles blocks the ventral and dorsal branches of the thoracic spinal nerves, with the subsequent spread of the injection laterally in the fascial plane resulting in the blockage of the lateral cutaneous branch of the intercostal nerve[51].

TRLB has been shown to be associated with reduced perioperative fentanyl consumption, post-extubation pain scores, time to first analgesia request, extubation time, and intensive care unit length of stay in children undergoing open-heart surgery via median sternotomy. Furthermore, TRLB has been reported to be simpler, easier to administer, and theoretically safer than thoracic epidural analgesia and paravertebral blocks because the blocking needle is placed toward the vertebral lamina, thus away from major vessels, pleura, and dura[52]. A recent network meta-analysis which examined the RA approaches in paediatric cardiothoracic surgery demonstrated that the most significant decline in opioid consumption was observed in TRLB[17].

Table 2

Local Anesthetics in Pediatric Thoracic Wall Fascial Plane Blocks

Local Anesthetic	Concentration	Recommended Dose (max)	Typical Volume	Onset	Duration	Advantages	Disadvantages Precautions
Bupivacaine	0.25–0.375%	2.0–2.5 mg/kg	0.5–1.0 ml/kg per side	10–20 min	6–12 h	Long duration; good spread in fascial planes	Higher cardiotoxicity risk in infants; must calculate carefully
Levobupivacaine	0.25–0.375%	2.0–2.5 mg/kg	0.5–1.0 ml/kg	10–15 min	6–12 h	Lower cardiotoxicity than bupivacaine; safer profile	Expensive; similar kinetics to bupivacaine
Ropivacaine	0.2–0.5%	2.5–3.0 mg/kg	0.5–1.0 ml/kg	10–15 min	5–10 h	Lower motor block; safer cardiac profile	Slightly shorter duration than bupivacaine
Lidocaine	1–1.5%	4.5–5 mg/kg	0.5 ml/kg	3–5 min	1–2 h	Very rapid onset; useful for short procedures	Short duration; risk of toxicity in infants
Mepivacaine	1%	5–6 mg/kg	0.5 ml/kg	5–10 min	2–3 h	Intermediate duration; good safety profile	Less commonly used in pediatrics

Table 3

Pediatric Volume Guidelines by Block Type

Block Type	Suggested Volume (per side)	Local Anesthetic Choice
Parasternal Block (Superficial / Deep PIP)	0.2–0.5 ml/kg	0.25% bupivacaine
Interpectoral Plane and Pectoserratus Plane Blocks	0.5–0.8 ml/kg	0.25% ropivacaine or bupivacaine (Max total ~20 ml)
Serratus Anterior Plane Block	0.5–1.0 ml/kg	0.2–0.25% ropivacaine or bupivacaine
Erector Spinae Plane Block	0.5–1.0 ml/kg	0.25–0.375% ropivacaine or bupivacaine
Midpoint Transverse Process Block Thoracic Retrolaminar Block Multiple-Injection Costotransverse Block	~0.3–0.5 ml/kg per level	0.2–0.25% ropivacaine or bupivacaine

4.4. Multiple-Injection Costotransverse Block

As with the MTPB and TRLB, the multiple-injection costotransverse block (MICB) involves the injection of LA in the proximity of the paravertebral space. The block needle is inserted through the use of ultrasound guidance, with the objective of reaching the inferior border of the superior rib anterior to the intertransverse ligament, just posterior to the superior costotransverse ligament[21]. Somani et al.[53] compared the efficacy of MICB administered for analgesia following sternotomy in paediatric cardiac surgery patients, with the ESPB. The study concluded that MICB is as effective as ESPB in the management of pain following sternotomy.

4.5. Local Anesthetic Dose and Toxicity

In all facial plane blocks, large volumes of diluted LA are used to expand the facial planes and promote spread across multiple dermatomes. However, the use of large volumes of LA and its rapid absorption in these blocks may increase the risk of systemic absorption and LA toxicity. Since RA is administered under general anaesthesia in paediatric patients, the clinical symptoms of LA toxicity cannot be observed. To prevent the risk of intravascular injection, LA should be administered in small amounts, such as 0.1–0.2 ml/kg, with intermittent aspiration, followed by careful monitoring of haemodynamic and electrocardiographic changes[54].

The anatomical development of children may cause differences in the spread of LA across tissue planes, and the pharmacokinetic properties of each block differ from one another. However, the lack of pharmacokinetic data on this subject prevents the recommendation of absolute doses (both bolus and infusion) in children. Therefore, in paediatric patients, dose adjustment should be made at the lowest possible volume and effective concentration, adhering to the maximum recommended LA dose per kilogram[55] (Table 2, table 3). The clinical evidence level is insufficient due to the small number of patient groups in RA studies in paediatric cardiac surgery and the diversity in practice. Future studies examining serum local anaesthetic levels to determine dosage strategies may offer a resolution to the concerns raised.

5. Conclusion

A substantial body of research, both prospective and retrospective, has reported that the utilisation of regional anaesthesia in paediatric cardiac surgery results in reduced pain scores, diminished intraoperative and postoperative opioid utilisation, abbreviated extubation times, and reduced hospitalisation durations. These findings are of particular significance in patients who comply with ERAS protocols. Furthermore, given that RA methods do not cause major complications, they are recommended as part of a multimodal analgesic regimen for all paediatric patients undergoing sternotomy. However, further research is required to determine the optimal block, LA type, dose, and timing. Moreover, large-scale studies comparing different block types in different age groups, especially in neonatal patients, are necessary.

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