REVIEW

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Regional anesthesia as part of enhanced recovery strategies in pediatric cardiac surgery

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Purpose of review

The purpose of this review article was to highlight the enhanced recovery protocols in pediatric cardiac surgery, including early extubation, rapid mobilization and recovery, reduction of opioid-related side effects, and length of pediatric ICU and hospital stay, resulting in decreased costs and perioperative morbidity, by introducing recent trends in perioperative anesthesia management combined with peripheral nerve blocks.

Recent findings

Efficient postoperative pain relief is essential for realizing enhanced recovery strategies, especially in pediatric patients. It has been reported that approaches to perioperative pain management using additional peripheral nerve blocks ensure early extubation and a shorter duration of ICU and hospital stay. This article provides an overview of several feasible musculofascial plane blocks to achieve fast-track anesthesia management for pediatric cardiac surgery.

Summary

Recent remarkable advances in combined ultrasound techniques have made it possible to perform various peripheral nerve blocks. The major strategy underlying fast-track anesthesia management is to achieve good analgesia while reducing perioperative opioid use. Furthermore, it is important to consider early extubation not only as a competition for time to extubation but also as the culmination of a qualitative improvement in the outcome of treatment for each patient.

Keywords

enhanced recovery after surgery, fast-track anesthesia, pediatric cardiac surgery, peripheral nerve block, postoperative pain relief

INTRODUCTION

Prolonged postoperative ventilatory management with delayed extubation is still common in many centers performing pediatric cardiac surgery worldwide. The reasons for using this approach are as numerous as there are centers. Together with short-acting anesthetic drugs and improved surgical and perfusion protocols, early extubation is becoming increasingly common in these patients.

Enhanced recovery after surgery (ERAS) protocols are applied not only in pediatric cardiac surgery but also in many fields and surgical procedures [1,2]. The main issue with Fast Track or ERAS strategies is not only extubation in the operating room but also perioperative management strategies leading to subsequent postoperative management in the pediatric intensive care unit (PICU) [3]. Nevertheless, in the current situation, intravenous administration of opioids is still the main treatment strategy for perioperative pain management for cardiac surgery in many facilities because of the potential for bleeding or hematoma formation in the epidural space [4▪▪]. However, merely aiming to overdo it with systemic intravenous administration of opioids also raises concerns about opioid-related side effects and delayed extubation [5,6]. It has been also reported that a significant percentage of pediatric patients develop chronic pain following cardiac surgery, concerning hyperalgesia and allodynia around the surgical wound [7▪▪].

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KEY POINTS

- The purpose of this review article is to break away from the indiscriminate continuation of old-fashioned treatment strategies that run counter to fast-track anesthesia strategies in pediatric cardiac surgery by introducing recent trends in perioperative anesthesia management combined with peripheral nerve blocks.
- Efficient postoperative pain relief is essential to realize fast-track anesthesia strategies and is important, especially in pediatric patients.
- Recent trends and guidelines for perioperative management in cardiac surgery recommend multimodal approaches to pain management, including regional anesthesia techniques, to reduce the use of opioids.
- The targets of the peripheral nerve block for a median sternotomy or intercostal incision are branches of the intercostal nerve at any approachable site.
- The combination of a peripheral nerve block (musculofascial plane block) is very promising for reducing intraoperative opioid consumption, time to extubation, postoperative pain score, and length of hospital stay after pediatric cardiac surgery.

The purpose of this review article is to highlight the treatment strategies of ERAS protocols in pediatric cardiac surgery, including early extubation [8▪], rapid mobilization and recovery, reduction of opioid-related side effects [4▪▪,9▪▪], and reduction in the length of PICU and hospital stay, resulting in decreased costs and perioperative morbidity [10▪], by introducing recent trends in perioperative anesthesia management combined with peripheral nerve blocks.

REQUIREMENTS FOR ERAS IN PEDIATRIC CARDIAC SURGERY

In adults, there is broad agreement that a patient is medically suitable to leave the hospital when the following conditions are true: he/she can eat and drink to fulfill daily needs; the bowels are moving; pain is controlled by oral analgesics; he/she is capable of sufficient mobility for self-care; there are no complications requiring hospital care [11▪]. In pediatric cardiac surgery, there is no consistent agreement on the endpoints of ERAS management. The American Association for Thoracic Surgery recently founded a working group focused on a comprehensive perioperative approach to facilitate enhanced recovery in children following pediatric cardiac surgery [3]. They pointed out that ERAS protocols may be applied across all procedural complexity levels. Moreover, postoperative pain relief, sufficient spontaneous respiration, and adequate sedation are essential to realizing safe fast-track anesthesia strategies, especially in pediatric cardiac patients. Postoperative pain therapy is mandatory to avoid a long stay in the ICU or PICU. In addition, recent trends and guidelines for perioperative management in cardiac surgery recommend multimodal approaches to pain management, including regional anesthesia techniques, to reduce the use of opioids [9▪▪,12▪,13▪]. Indeed, it has been reported that such approaches to perioperative pain management using additional peripheral nerve blocks ensure early extubation and shorter duration of ICU and hospital stay [5].

ADVANTAGES OF EARLY EXTUBATION IN CHILDREN FOLLOWING CARDIAC SURGERY

First, it should be noted that reducing the amount of time pediatric patients spend alone in an environment away from their parents is an important factor in maintaining their motivation and cooperative attitude toward subsequent treatment.

Ensuring safe early extubation is the first step toward achieving ERAS management. Early extubation is one of the greatest advantages from a hemodynamic standpoint, when postoperative left heart failure is not severe, as it allows for a more stable hemodynamic state during the time zone of the greatest risk of heart failure, usually 6–10 h following open heart surgery using cardiopulmonary bypass (CPB). The preload to the heart is decreased in the inspiratory phase of mechanical ventilation owing to an increase in intrathoracic pressure. Although this effect of mechanical ventilation is more pronounced in Glenn and Fontan patients, in whom central venous pressure is the driving force of the pulmonary circulation [14▪▪], this is not limited to single-ventricle patients [15▪▪]. Finally, the improvement in blood circulation is the greatest advantage of early extubation following cardiac surgery [8▪,16].

TARGET PATIENT GROUP FOR ENHANCED RECOVERY FOLLOWING PEDIATRIC CARDIAC SURGERY

There are no clear standards for the indication of early extubation following pediatric cardiac surgery; therefore, the indication may vary from institution to institution. Table 1 shows the guidelines for patients at our institution who were to be extubated in the operating room and those who were to be extubated early postoperatively in the ICU. Even for patients in whom fast-track anesthesia management

Table 1. The guidelines for patients for fast-track anesthesia management at our institution

Patients undergoing fast-track anesthesia management and extubated on-table in the operating room
secundum ASD, sinus venosus ASD, partial anomalous pulmonary venous return, VSD/AVSD with sufficient pressure gradient between ventricles
TOF correction
Aortic valve procedures, pulmonary valve procedures, RV-PA conduit replacement
CoA > 3 months, PDA > 3 months
Age > 28 days
CPB time < 180 min
Glenn procedure, Fontan procedure
Patients undergoing fast-track anesthesia management but extubated in the PICU/ICU
Patients remaining bleeding concerns
CoA < 3 months, PDA < 3 months
CPB time > 180 min
Persistent arrhythmias or pacemaker-dependent
Hemodynamic instability

ASD, atrial septal defect; VSD, ventricular septal defect; AVSD, atrioventricular septal defect; TOF, tetralogy of Fallot; RV-PA, right ventricle-to-pulmonary artery; CoA, coarctation of the aorta; PDA, patent ductus arteriosus; CPB, cardiopulmonary bypass; PICU, pediatric intensive care unit.

was performed intraoperatively, the absence of postoperative bleeding and hemodynamic stability are prerequisites for extubation in the operating room.

EARLY EXTUBATION AND PULMONARY HYPERTENSION

When considering the risk factors for unfavorable outcomes, pulmonary hypertension is one of the major risk factors for pediatric anesthesia according to the surgery/anesthesia-related postoperative mortality [17■]. Pulmonary hypertension or a better risk for possible postoperative pulmonary hypertension crisis was often cited as an argument for prolonged postoperative ventilation in children after cardiac surgery. However, a recent study revealed that the reasons for reintubation after extubation in the operating room following pediatric cardiac surgery were bleeding or insufficient respiration but not pulmonary hypertension crisis [18].

The increase in pulmonary vascular resistance is a critical factor against successful early extubation in pediatric patients with congenital heart disease. Among the parameters that can be regulated by anesthesia machines and ventilators, inhaled oxygen concentration, mean airway pressure, positive end-expiratory pressure (PEEP) level, and minute volume affect the incoming vascular resistance. The decrease in inhaled oxygen concentration causes pulmonary vasoconstriction [hypoxic pulmonary vasoconstriction (HPV)], which results in an oxygen concentration-dependent increase in the pulmonary vascular resistance [19■■]. Increased arterial blood carbon dioxide concentration and acidosis dilate cerebral and other blood vessels but constrict the pulmonary vessels [20■■]. Avoiding atelectasis is a key factor in perioperative anesthesia management to ensure successful early extubation because atelectasis increases pulmonary vascular resistance due to the effects of HPV, increased arterial blood carbon dioxide concentration, and acidosis. It has been reported that applying a PEEP of approximately 6 cmH_2O is effective in preventing atelectasis [21■■,22■■], and that the alveolar recruitment maneuver during open-heart surgery has improved postoperative lung compliance and oxygenation [23■■].

WHEN TO AVOID EARLY EXTUBATION

Mechanical ventilatory management should be continued after surgery, and the postoperative course should be carefully monitored in cases with a high risk of postoperative pulmonary hypertension or palliative procedures in which the pulmonary and systemic circulations remain in parallel (e.g. pulmonary artery banding, Blalock–Taussig shunt, and Norwood procedure).

It is very important to recognize that the right heart system, both in terms of contractility and strength of the atrioventricular valve, is extremely vulnerable to increased afterload and can easily enter a state of right heart failure. The risk of postoperative pulmonary hypertension is not high in atrial septum defects [24▪▪], where there is only increased pulmonary blood flow and a low risk of increased pulmonary vascular resistance, or in mitral valve stenosis [25▪▪], where pulmonary venous pressure is only elevated as a result of increased left atrial pressure [26▪▪]. However, in conditions such as ventricular septum defect or atrioventricular septal defect [27▪], where both pulmonary blood flow and pulmonary vascular resistance are elevated, consideration must be given to the possibility of complications of postoperative pulmonary hypertension [26▪▪]. In addition, 21 trisomy is prone to early increased pulmonary vascular resistance [28▪▪], which is complicated by pulmonary hypertension in efficiency [29▪▪]; furthermore, the effect of nitric oxide inhalation on postoperative pulmonary hypertension is poor [30▪▪].

In pediatric patients with congenital heart disease whose postoperative hemodynamics are in parallel circulation and dependent on the balance between body and pulmonary vascular resistance, mechanical ventilatory management should be continued following surgery to actively manipulate the body and pulmonary vascular resistance to maintain systemic oxygen supply and to avoid increasing cardiac afterload as much as possible, while on-table extubation even after the Norwood procedure is reportedly possible [31▪▪].

In pediatric patients with congenital heart disease who do not require early extubation, especially those younger than 1–2 years of age, the risk of sinusitis is not as high as that in adults, and nasal intubation is considerable [32▪▪], as it has been reported to provide better fixation of the tracheal tube and is effective in preventing accidental extubations [33▪▪].

PAIN THERAPY BEYOND SYSTEMIC OPIOIDS FOR PEDIATRIC CARDIAC SURGERY

Target for perioperative pain management for cardiac surgery with median sternotomy as well as thoracotomy and intercostal approach: intercostal nerves

The target of the peripheral nerve block for a median sternotomy or intercostal incision is the anterior/ventral branches of the spinal cord, that is, the intercostal nerves. The intercostal nerves arise from the anterior rami of the thoracic spinal nerves and run between the innermost and inner intercostal muscles, branching off collateral and lateral cutaneous branches along the way, and finally become anterior cutaneous branches and are distributed in the lateral and front sides of the chest wall, respectively, innervating sensory supply to the skin, soft tissue, and muscle on the anterior aspect of the trunk, including the sternum [34,35▪,36▪,37▪]. Consequently, blocking the intercostal nerve at any approachable site is the theory of peripheral nerve block for cardiac surgery with median sternotomy, as well as the intercostal approach (Fig. 1 and Table 2).

Understanding the anatomy of the anterior body trunk to perform peripheral nerve blocks in cardiac surgery

The intercostal muscle layers are located between the ribs. The pectoralis major muscle lies over the ribs. The intercostal muscles consist of three layers: the external, internal, and innermost intercostal muscles [12▪]. However, it is difficult to identify each of these three layers on ultrasound images. The intercostal arteries, veins, and nerves are located on the lower margin of the ribs in the layer between the internal and innermost intercostal muscles. The transverse thoracic muscle lies below the innermost intercostal muscle [34,36▪,38]; however, the transverse thoracic muscle itself is very thin and may not be clearly identified on ultrasound images. In such cases, a high echoic ''white line'' below the intercostal muscle layer can be used as a guide, and the transverse thoracic muscle lies below this white line [37▪]. The pleura moving with mechanical ventilation or the pericardium and heart when the heart is visible is easily identified as a hyperechoic layer.

Peripheral nerve block from the anterior approach for cardiac surgery with median sternotomy: parasternal intercostal nerve block

The anterior branches of the Th2–Th6 internal nerves are associated with pain related to median sternotomy. According to a study, the blockade of these nerves close to the sternum is effective for pain management [12▪]. Furthermore, it has been reported that parasternal intercostal nerve block (PSB) showed significant efficacy for postoperative analgesia, requiring fewer opioids in the first 24 postoperative hours and no or less rescue dose of additional analgesics [39▪,40▪], and showed lower postoperative pain scores in pediatric patients [41▪] as well as adults [39▪]. Additionally, it was reported that the alveolar–arterial oxygen gradient and pH values were better in the PSB group than in the placebo group [40▪]. However, these studies showed no differences in the mechanical ventilation duration [39▪,40▪]. Another study comparing preoperative and postoperative ultrasound-guided PSB revealed that preoperative PSB

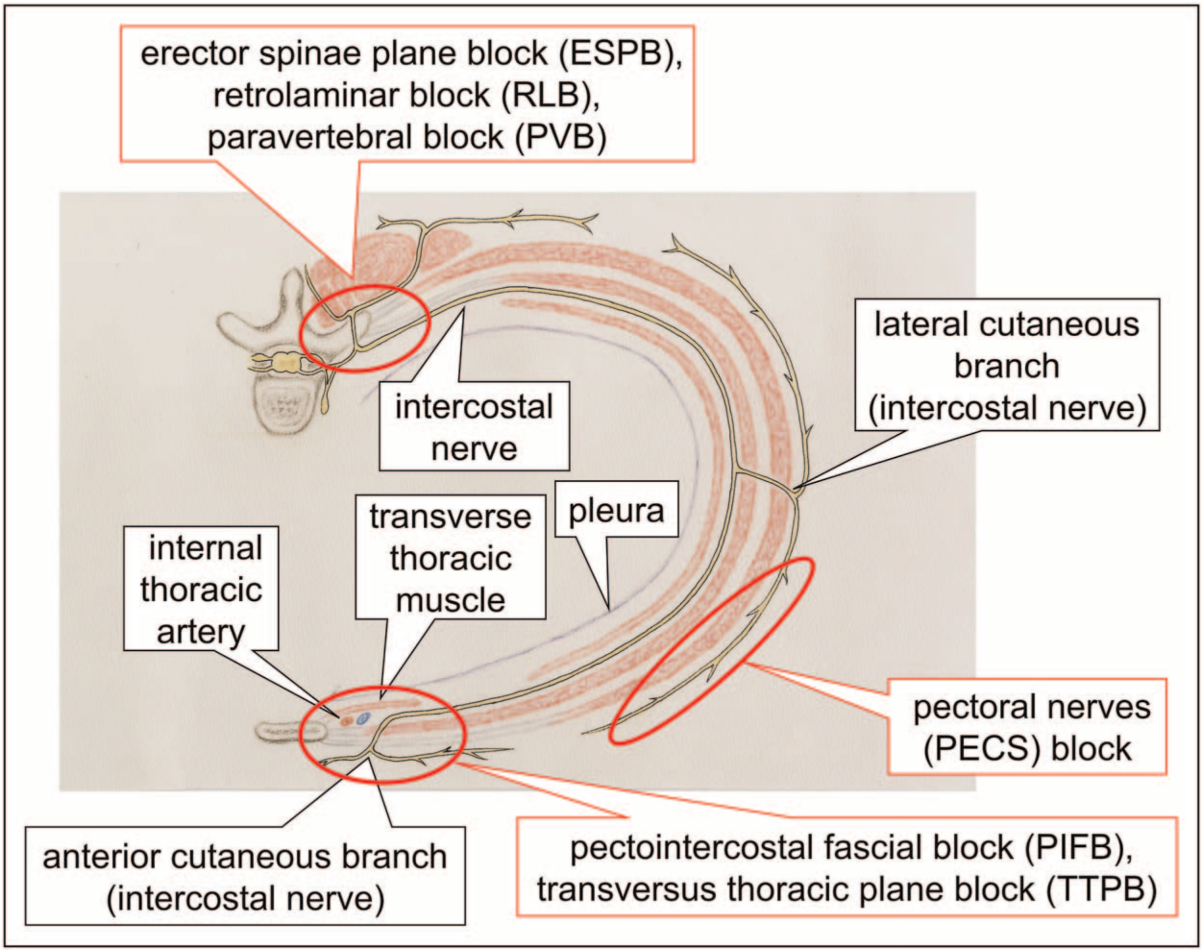

FIGURE 1. Schema of access points to the intercostal nerve blocks for perioperative pain management for cardiac surgery. Blocking the intercostal nerve at any approachable site is the theory of peripheral nerve block for cardiac surgery with median sternotomy as well as intercostal approach.

Table 2. Peripheral nerves affected by peripheral nerve blocks and available indications for cardiac surgery

Peripheral nerve block	Affected nerves	Surgical indications
PSB, PIFB, TTPB (performed in a supine position)	Anterior cutaneous branches of the intercostal nerves	Median sternotomy
PECS block (performed in a supine position)	Lateral cutaneous branches of the intercostal nerve	Surgical fields off the anterior thoracic midline Thoracotomy with intercostal approach
ESPB, RLB, PVB (performed in a lateral position)	Anterior and lateral cutaneous branches of the intercostal nerve	Median sternotomy Surgical fields off the anterior thoracic midline Thoracotomy with intercostal approach
RSB	Anterior cutaneous branches of the intercostal nerves in the upper abdomen level	Upper abdominal pain due to thoracic drain insertion Subcutaneous implantation of a defibrillator in the upper abdomen

The concentration (between 0.1 and 0.375%) and total dosage volume (maximum dose of ropivacaine: 3 mg/kg in a single block) of ropivacaine is calculated on the basis of the patient's body weight [41■]. PSB, parasternal intercostal nerve block;, PIFB, pectointercostal fascial block; TTPB, transversus thoracic plane block; PECS, pectoral nerves; ESPB, erector spinae plane block; RLB, retrolaminar block; PVB, paravertebral block; RSB, rectus sheath block.

reduced intraoperative opioid consumption and provided hemodynamic stability during cardiac surgery; however, total opioid requirement and pain score in the first postoperative hours were not affected [42▪]. Moreover, another interesting efficacy of preoperative PSB in reducing proinflammatory cytokine release during CPB as well as the intraoperative requirement of remifentanil and propofol in coronary artery bypass surgery has been reported [43]. Despite significant effectiveness in perioperative analgesia, PSB's biggest disadvantage is that multiple punctures are required 'theoretically' as the target intercostal nerves lie in the layer between the internal intercostal muscle and the innermost intercostal muscle in each intercostal space. To solve this disadvantage, the following two functional musculofascial planes are considered adequate approaches for PSB: pectointercostal fascial block (PIFB) and transversus thoracic plane block (TTPB) [44], where injected local anesthetics can spread widely along the fascial layer between muscles to cover multiple anterior branches of the intercostal level [36▪,37▪].

Pectointercostal fascial block and transversus thoracic plane block: aiming to enforce parasternal intercostal nerve block for multiple segments at once

Ultrasound-guided pectointercostal fascial block (PIFB) and transversus thoracic plane block (TTPB) can also be performed in a supine position as PSB. To enforce PSB for multiple segments at once, local anesthetic is injected into the layer between the pectoralis major muscle and the intercostal muscular layer in PIFB [35▪], and in the layer between the intercostal muscular layer and the transversus thoracis muscle in TTPB [36▪,37▪].

PIFB is considered a 'superficial version of the TTPB' and a simpler block than the TTPB because the local anesthetic is injected into the more superficial fascial layer and away from the internal thoracic artery (ITA) and pleura [34,38,45]. Numerous clinical validations of the reproducibility and safety of PIFB have been reported in adult patients [34,38,45,46▪,47–49]. PIFB has been reported to reduce opioid consumption and postoperative pain both at rest and during cough in the first 24 h following cardiac surgery [48]. In addition, PIFB reduces the time to extubation and length-of-hospital stay [49].

The efficacy of TTPB for cardiac surgery with median sternotomy is also being reported. In a retrospective investigation of pediatric patients, TTPB reduced intraoperative and postoperative 24 h fentanyl consumption, postoperative pain scales, and time to extubation; furthermore, TTPB was performed safely with no block-related complications [50]. It is also reported that the risk of block-related complications in TTPB is not different from that in PIFB [51▪]. ITAs are reported to be present just lateral to the sternum and can be identified using ultrasound as anechoic linear structures or by color Doppler mode in combination [38]. ITAs are easier to find when the ultrasound probe is placed on the chest wall transverse to the axis of the sternum, even so, they are not identified in all cases from our experience. One prospective, randomized, double-blind pilot study comparing the efficacy and safety of TTPB and PIFB showed similar effectiveness for postoperative morphine consumption, pain scores at rest and during coughing, and requirements for rescue analgesia in the first postoperative 24 h [52]. However, it has been reported that PIFB requires multiple punctures on each side to cover the entire length of the sternum because the injected local anesthetic does not spread as widely as TTPB [35▪].

Combination with rectus sheath block: considering upper abdominal pain due to thoracic drain

It should be considered that pain and discomfort following cardiac surgery can arise not only from the median sternotomy but also from the upper abdomen where the thoracic drain is inserted [37▪]. There is also a report on the combined use of PIFB and RSB in the subcutaneous implantation of a defibrillator [53]. The effects of combining rectus sheath block (RSB) have been well studied in PIFB and recently in pediatric cardiac patients with median sternotomy [54]. The combination of PIFB and RSB reduced intraoperative methadone administration dose, postoperative pain scores, and opioid consumption in the first 12 h after cardiac patients with median sternotomy, even though both pain scores and opioid consumption were subsequently equalized between the groups with and without the use of this combination, and the daily average opioid consumption decreased in the PIFB–RSB group [54]. In addition, the length of hospital stay was shorter without prolonging the time under general anesthesia in the PIFB–RSB group. Moreover, no complications associated with the block and safety have been reported [54].

The combination of TTPB and RSB for cardiac surgery with median sternotomy in adult and pediatric patients has also been reported. The details of how to perform the RSB and TTPB are described in detail in our previous article with figures [37▪].

Pectoral nerves II block: aiming for analgesia in areas slightly displaced outward from the anterior thoracic midline

There are cases of the atrioventricular block following congenital heart disease surgery, in which an implantable pacemaker is implanted subcutaneously in the anterior thoracic wall. These pacemakers or defibrillators require periodic battery changes, and in some cases, lead adjustments or additions may be necessary if they are not sufficiently effective. These surgical fields are off the anterior thoracic midline and cannot be completely covered by the peripheral nerve block focused on the median sternotomy described above. In such cases, the pectoral nerves (PECS) block [55▪], particularly the PECS II block, which can block the lateral cutaneous branches of the intercostal nerve innervating the sensory supply to the lateral part of the chest wall [56▪], is considerable. When the ultrasound probe is placed on the chest wall from the lateral clavicle to the anterior subaxillary level such that the short-axis image of the third or fourth rib is depicted, the serratus anterior, pectoralis minor, and pectoralis major lie over the rib in that order. The local anesthetic is injected into the layer between the pectoralis major and minor muscles in PECS I [55▪] and into the layer between the pectoralis minor and serratus anterior muscles in PECS II [56▪]. PECS II is recommended because of its superior effectiveness compared with PECS I [57▪]. PECS II is very simple to perform: the puncture needle is inserted in a long-axis approach toward the rib being depicted, and once the puncture needle reaches the rib, a local anesthetic is injected after the aspiration test. The local anesthetic was visible on ultrasound, spreading into the layer between the pectoralis minor and serratus anterior muscles.

This PECS block can be applied as a single injection as well as a catheter-based infusion for surgeries with thoracotomy, such as minimally invasive cardiac surgery with an intercostal approach in adult patients [58,59].

Peripheral nerve block from the posterior approach for cardiac surgery: erector spinae plane block, retrolaminar block, and paravertebral block

Considering the idea of a block somewhere in the intercostal nerve run derived from the spinal cord, the erector spinae plane block (ESPB), the retrolaminar block (RLB), and the paravertebral block (PVB) could be considered as options. Because the intercostal nerve is blocked at a level not far from the spinal cord, both the anterior branches and the lateral cutaneous branches of the intercostal nerve can be blocked at once. Thus, these peripheral nerve blocks can be applied to cardiac surgeries with median sternotomy as well as surgical fields off the anterior thoracic midline. The ESPB targets the tips of transverse processes, whereas the RLB targets the laminae [60]. The PVB targets the paravertebral space [61]. The injected local anesthetic spreads several segments cephalad and caudal along the musculofascial plane between the paraspinal back muscles and underlying thoracic vertebrae [60]. Indeed, improvements in perioperative opioid consumption and postoperative pain management have also been reported with ESPB [62▪,63] and PVB [61] in cardiac surgery with median sternotomy in pediatric patients. The efficacy of ESPB and RLB is reported to be equivalent to postoperative analgesia following anterior chest wall surgery [64]. According to a report, preoperative bilateral single-shot ESPB in cardiac surgery reduced intraoperative increase of lactate and postoperative C-reactive protein values [65]. The rate of failure (incorrect placement of catheter) and complications in the PVB group were significantly lower than that of the thoracic epidural catheter group. The only disadvantage may be that, unlike the blocks presented above, these blocks require the patient to be placed in a lateral position. However, ESPB and RLB can also be easily performed in a blinded fashion by injecting a local anesthetic at the point where the puncture needle is applied to the transverse process of the vertebra (Fig. 2), while the real-time ultrasound guidance technique is essential for PVB [61].

FIGURE 2. Erector spinae plane block performed in a blinded fashion in a lateral position. Erector spinae plane block (ESPB) and retrolaminar block (RLB) can also be performed in a blinded fashion by injecting a local anesthetic at the point where the puncture needle is applied to the transverse process of the vertebra.

Summary of peripheral nerve blocks that may be combined in anesthesia management for pediatric cardiac surgery

Recent remarkable advances in combined ultrasound techniques in anesthesiology have made it possible to perform a variety of peripheral nerve blocks. Indeed, the use of musculofascial plane blocks, which allow local anesthetics to be applied over a wide area, has become routine in clinical practice for perioperative anesthesia management in the cardiac surgery, as this method relieves concerns related to intraoperative heparinization. Furthermore, it is recommended that these peripheral nerve blocks should be performed before surgery begins, that is, before the nociceptive stimulation by the first incision is applied, in terms of preemptive analgesia [37▪].

CONCLUSION

The major strategy underlying fast-track anesthesia management in cardiac surgery is to achieve two seemingly opposing elements: good analgesia while reducing perioperative opioid use. In this review article, we introduced a combination of various peripheral nerve blocks as a method of achieving Fast Track in pediatric cardiac surgery that can be performed in actual clinical practice. In ERAS in pediatric cardiac surgery, it is important to consider early extubation not only as a competition for time to extubation, but also as the culmination of a qualitative improvement in the outcome of treatment for each patient.

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Conflicts of interest

There are no conflicts of interest.

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