Best Practice & Research Clinical Anaesthesiology 33 (2019) 387–406

Contents lists available at ScienceDirect

Best Practice & Research Clinical Anaesthesiology

journal homepage: www.elsevier.com/locate/bean

2

Regional anesthesia considerations for cardiac surgery

Henry Liu, MD, Professor [a,*],
Patrick I. Emelife, MD, Senior Resident [b],
Amit Prabhakar, MD, MS, Assistant Professor [c],
Vanessa Moll, MD, PhD, Assistant Professor [c],
Julia B. Kendrick, MD, Senior Resident [b],
Allan T. Parr, BS, Senior Medical Student [d],
Farees Hyatali, MD, Senior Resident [e],
Thakur Pankaj, MD, Resident [e],
Jinlei Li, MD, PhD, Associate Professor [f],
Elyse M. Cornett, PhD, Assistant Professor [e],
Richard D. Urman, MD, MBA, Associate Professor [g],
Charles J. Fox, MD, Professor & Chairman [e],
Alan D. Kaye, MD, PhD, Professor, Program Director & Chairman [b]

[a] *Department of Anesthesiology, Drexel University College of Medicine, Reading Hospital-Tower Health System, 245 N. 15th Street, Philadelphia, PA 19102, USA*
[b] *Department of Anesthesiology, LSU Health Sciences Center, Room 656, 1542 Tulane Ave., New Orleans, LA 70112, USA*
[c] *Department of Anesthesiology, Division of Critical Care, Emory University School of Medicine, 550 Peachtree Street, Atlanta GA 30308, USA*
[d] *LSU Health Shreveport, 1501 Kings Highway, Shreveport LA 71103, USA*
[e] *Department of Anesthesiology, LSU Health Shreveport, 1501 Kings Highway, Shreveport LA 71103, USA*
[f] *Department of Anesthesiology, Yale University School of Medicine, New Haven, CT 06510, USA*
[g] *Department of Anesthesiology, Perioperative and Pain Medicine, Brigham and Women's Hospital, Boston MA 02115, USA*

* Corresponding author.
E-mail addresses: henryliupa@gmail.com (H. Liu), pemeli@lsuhsc.edu (P.I. Emelife), amit.prabhakar@emory.edu (A. Prabhakar), vanessa.moll@emory.edu (V. Moll), jkend3@lsuhsc.edu (J.B. Kendrick), aparr@lsuhsc.edu (A.T. Parr), fhyata@lsuhsc.edu (F. Hyatali), pthaku@lsuhsc.edu (T. Pankaj), jinlei.li@yale.edu (J. Li), ecorne@lsuhsc.edu (E.M. Cornett), rurman@bwh.harvard.edu (R.D. Urman), cfox1@lsuhsc.edu (C.J. Fox), akaye@lsuhsc.edu (A.D. Kaye).

https://doi.org/10.1016/j.bpa.2019.07.008
1521-6896/Published by Elsevier Ltd.

Keywords:
nerve blocks
anesthesia
regional anesthesia
thoracic nerves
chest wall

Pain is a significant consequence of cardiac surgery and newer techniques in cardiac anesthesia have provided an impetus for the development of multimodal techniques to manage acute pain in this setting. In this regard, regional anesthesia techniques have been increasingly used in many cardiac surgical procedures, for the purposes of reducing perioperative consumption of opioid agents and enhanced recovery after surgery. The present investigation focuses on most currently used regional techniques in cardiac surgical procedures. These regional techniques include chest wall blocks (e.g., PECS I and II, SAP, ESB, PVB), sternal blocks (e.g., TTMPB, PSINB), and neuraxial blocks (e.g., TEA, high spinal anesthesia). The present investigation also summarizes indications, technique, complications, and potential clinical benefits of these evolving regional techniques. Cardiac surgery patients may benefit from application of these regional techniques with well controlled indications and careful patient selections.

Introduction

Cardiovascular disease accounts for more than one-third of deaths globally [1] and more than $300 billion in direct and indirect costs in the United States alone [2]. It is very likely to remain the leading cause of mortality and morbidity for the elderly worldwide. The total number of elderly citizens in the United States will almost double between 2017 and 2060 [3]. The increase in elderly population will undoubtedly increase the prevalence of cardiovascular diseases, so will the volume of cardiovascular interventional procedures [4]. Patients undergoing cardiovascular surgery often involve both extremes of age. Though congenital cardiac surgery is relatively stable in incidence, cardiac surgery and interventional procedure for congenital heart disease have been evolving. Minimally invasive cardiac procedures such as transcatheter aortic valve replacements (TAVR) are enabling older and sicker patients to undergo interventional/surgical procedures. In late 1980s and early 1990s, high-dose opiate anesthetic strategies that promoted cardiovascular/hemodynamic stability were very common practice with the consequence of significantly longer time of postoperative mechanical ventilation in the intensive care unit (ICU), especially before fentanyl became available in clinical utilization. Use of fentanyl significantly shortened the postoperative intubation time and length of ICU stay in cardiac surgery patients. Opioid doses in the perioperative care of cardiac surgery patient have gone through a process of gradual and constant decline, due to several reasons, the economic requirement to shorten postoperative intubation times and length of ICU stay, the sociopolitical efforts to curb the opioid crisis which may be associated with perioperative use of narcotics. Several countries are currently battling “opioid epidemics” related to uncontrolled illegal market of heroin, inappropriate prescription of opioid type medications for chronic pain patients and the misuse of opioids in postsurgical patients. Enormously strong advocacy for minimal or opioid-minimizing enhanced recovery protocols has been steadily gaining popularity in perioperative settings. All of these has led to the multimodal analgesia approach in perioperative care. Neuraxial and peripheral nerve blocks have become essential components of these multimodal analgesic protocols [5] (see Figs. 1–3).

The ever-tightening human and financial resources in the health care system have also pushed regional anesthetic techniques to be increasingly used as part of an opioid-sparing, multimodal, pain regimen during pediatric and adult cardiac surgery in order to promote early extubation, reduce postoperative complications, minimize the length of ICU and hospital stay, and reduce overall cost of perioperative care [6]. Interestingly, the use of regional anesthesia techniques in cardiac surgery dates back to 1954 when one of the first heart surgeries was performed under thoracic epidural analgesia [7]. Neuraxial analgesia in cardiac surgery has been described for decades [8,9]. Advantages of thoracic epidural

Fig. 1. External photograph showing lateral to medial in-plane approach to transversus thoracis muscle plane block in the sternal region [57].

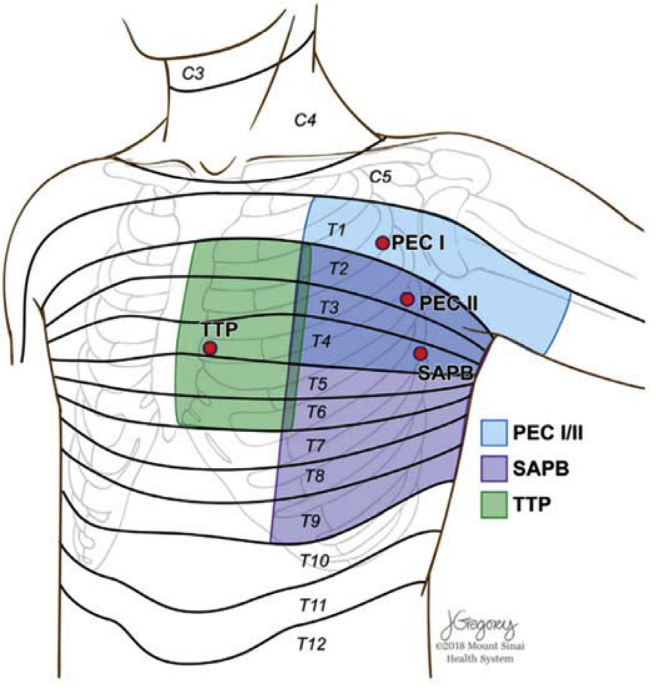

Fig. 2. Illustration of the chest wall anatomy including suggested regional block insertion sites and respective area and dermatomal distribution of expected sensory block [64].

analgesia include decreased incidence of cardiovascular events (stroke, myocardial ischemia) [8,10,11].], fewer respiratory complications, decreased incidence of renal failure, lower infection rates, shorter ICU length of stay, decreased cost of anesthesia, and earlier hospital discharge [11]. Another advantage of thoracic epidural analgesia is the ability to provide analgesia continuously throughout the perioperative period. Multiple clinical trials have confirmed the safety of thoracic epidurals [12], but remaining

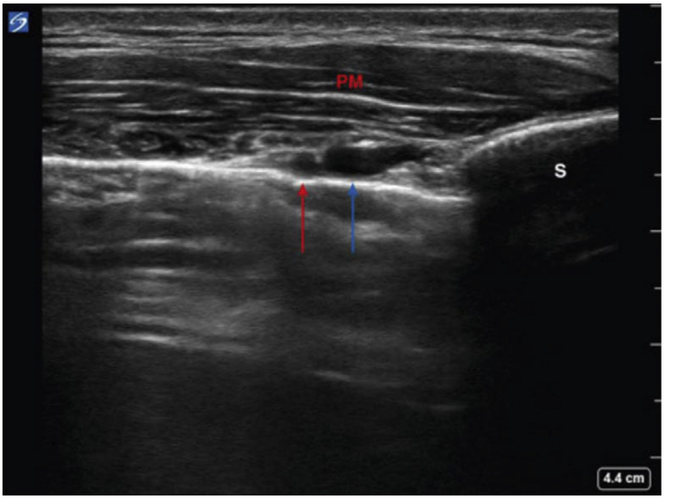

Fig. 3. Short axis view of the internal mammary artery (red arrow) and internal mammary vein (blue arrow) in the third intercostal space adjacent to the sternum (S) and pectoralis major (PM) muscle [57].

concerns over spinal and epidural hematomas and other potential complications have hindered its widespread adoption and still represent an ongoing controversy [13]. Additionally, the risk of often-existed post-cardiopulmonary bypass coagulopathy further complicates the use of neuraxial techniques. Concurrent aspirin use with systemic heparinization is a known risk factor for epidural hematoma after neuraxial instrumentation [14,15]. High spinal anesthesia is another neuraxial technique infrequently used by cardiac anesthesiologists. One worthy-mentioning advantage of a high spinal technique might be a blunted stress response [16] and a lower risk of spinal or epidural hematoma with the use of a small (27G) needle. A Canadian group has recently described their high thoracic spinal technique in practice for over 20 years with more than 10,000 patients without a single spinal or epidural hematoma [17]. The most commonly administered block of the paraxial nervous system is probably the paravertebral block (PVB). Although the anatomy of paravertebral space was known for many years, reproducible successful PVB became achievable routinely only recently due to the ability of the operator to locate the paravertebral space and avoid damaging the pleura [18]. Recently the ultrasound-guided PVB has been shown to be a safe and effective analgesic method compared with thoracic epidural analgesia [19,20]. The advantages from PVB include the hemodynamic stability when compared to thoracic epidural analgesia [21] and less nausea, hypotension, and urinary retention [20].

With the advent of minimally invasive cardiac surgery, fast track anesthesia techniques and ERAS protocols [6], multimodal analgesia including the use of regional anesthesia techniques moved back into the focus with an emphasis on blocking peripheral nerves in neural planes under ultrasound guidance. Chest wall blocks are newer, simpler alternatives to neuraxial analgesic techniques. Blanco initially described the pectoralis fascial block (PECS) I to provide anesthesia to the pectoral muscles and its modification (PECS II) to further provide anesthesia to the lateral chest wall in breast surgery [22,23]. The use of PECS blocks in cardiac surgery has recently been described as alleviating pain and coughing [24–26].

Another regional technique related to PECS is the serratus anterior plane (SAP) block that covers the hemithorax [27]. The SAP block has been mainly utilized in thoracic surgical procedures [28–30]. Recently, SAP, PECS II and intercostal nerve blocks (ICNB) were found to be equally efficacious in pediatric cardiac surgery with the former two having the benefit of extended duration [31].

A newer addition to the growing number of fascial blocks is the erector spinae block (ESB) [32]. Based on a cadaveric study, the ESB might have the advantage to offer analgesia for a median sternotomy [33]. This analgesic coverage would make the ESB a PVB by proxy in clinical practice [34]. Initial case reports and clinical studies in cardiac surgery patients have shown the safety of its use and promising analgesic efficiency [35–37]. ESB has also been successfully used in transapical transcatheter aortic valve implantation [38]. One of the most important reasons that fascial plane blocks are readily embraced by many anesthesia practitioners is the presumed better safety profile compared with neuraxial techniques; they are easy to administer, especially with the use of ultrasound; and they have fewer associated side effects. However, even peripheral nerve blocks may potentially pose some risks in cardiac surgery patients. The lack of laterality could require bilateral blocks for a standard sternotomy which significantly increases the risk of high local anesthetic plasma concentrations [39].

Patients on oral anticoagulant and antiplatelet drugs, two commonly used drugs in cardiac surgery patients, are at increased risk for hematoma formation as described in a large clinical trial using ultrasound-guided pectoralis blocks for breast surgery [40]. The most recent American Society of Regional Anesthesia and Pain Medicine (ASRA) guidelines on regional anesthesia in patients receiving antithrombotic therapy acknowledge that the risk after plexus and peripheral techniques remains undefined and recommends in coagulopathic patients that neuraxial guidelines are applied to deep plexus or peripheral blocks. For other plexus or peripheral techniques, management depends on site compressibility, vascularity, and consequence of bleeding [15]. Regional anesthesia technique, both neuraxial and peripheral, is an essential part of a multimodal analgesic regimen in traditional and fast track cardiac surgery patient. It also serves as a rescue technique for postoperative patient with poor pain control. Table 1 summarizes the benefits and current controversies of regional anesthesia in cardiac patient (see Table 1).

Chest wall blocks in cardiac surgery

Innervation of chest wall is mainly via anterior division of thoracic Intercoastal nerves from T2 to T6. Axillary apex is supplied by Intercostobrachialis nerve (branch of T2). Pectoralis muscles are supplied by Lateral pectoral nerve (C5-C7) and Medial pectoral nerve (C8-T1). Long thoracic nerve (C5-C7) supplies Serratus anterior and Thoracodorsal nerve (C6-C8) supplies Latissimus dorsi. As per the American Society of Anesthesiologist (ASA) 2016 guidelines, Enhanced Recovery After Surgery (ERAS) which forms an integral part of Perioperative Surgical Home (PSH); it is recommended to use multimodal opioid sparing approach for management of postoperative pain. In the constantly evolving field of anesthesiology, the same can be implemented to cardiac surgeries as well. Conventional use of Opioids leads to increased side effects, not limited to nausea, vomiting, clouded sensorium and respiratory depression amongst others. Herein, we describe availability of numerous regional blocks that have improved postoperative outcome after cardiac surgery with improved lung volumes and decreased incidence of atelectasis and ventilator dependence [6]. Various blocks that can be employed

Table 1
Benefits and risks of regional anesthesia in cardiac surgery [8,10,11,15,16,24].

	Benefits	Controversies
Neuraxial Blockade (thoracic epidural, spinal)	↓↓opiate requirements ↓Pain scores ↓Pulmonary complications ↓ stroke ↓ myocardial ischemia blunted stress response ↓ renal failure ↓ infection rate ↓ ICU stay ↓ cost of anesthesia earlier hospital discharge	Risk of spinal/epidural hematoma Timing of epidural placement and discontinuation in relation to anticoagulants
Peripheral Blockade (PECS, SAB, ESB[a])	Hemodynamic stability High safety profile Opioid sparing Improving coughing	Possibility of placement while on anti-dual platelet therapy or anticoagulated
Paravertebral Block	Hemodynamic stability Less nausea and urinary retention compared to thoracic epidurals	Mostly neuraxial ASRA guidelines are used

[a] ESB has not been classified formally yet by ASRA in terms of safety for a superficial plexus block (versus deep or neuraxial) which account for site vascularity, compressibility, and consequences of bleeding [15].

Table 2
Essentials of performing transversus thoracis muscular plane block [57].

Anatomy	One or two veins usually flank either side of the IMA the transversus thoracic muscle is about 1–2 mm in thickness ICN branches travel adjacent to the mammary vessels
Image orientation	The pectoralis major & internal intercostal muscle insert on the lateral edge of the sternum
Position	Supine
Operator	Standing on the side of the table
Display	Across the table
Transducer	High frequency linear, 25–50 mm footprint
Initial depth setting	30 mm
Needle	21-25 gauge, 38–50 mm in length
Anatomic location	Begin by scanning the parasternal region in transverse view. Adjust the image to identify an intercostal interspace & the internal mammary vessels
Approach	Transverse view, in-plane from lateral to medial Place the needle tip between the internal intercostal & transverse thoracis muscles
Sonographic assessment	Displacement of the pleura can be seen with injection Injection can track in a cephalon-caudal fashion between intercostal interspaces (SAX slide or LAX view)
Anatomic variations	Some anatomic variation of the IMA & IMV Accessory sternalis muscle (about 6% of normal subjects) Pectus excavatum (and other chest wall deformities) Long, jointed xyphoid process

for the postoperative reduction in pain after cardiac surgery includes bilateral Pectoralis I/II (PEC I/II), Erector Spinae (ESB), Serratus Anterior Plane (SAPB) and the Paravertebral (PVB) Block [6].

Regional blocks are simple interfascial infiltrative technique that not only improves postoperative pain control but also, reduce postoperative requirements for opioid, improves lung function parameters including reduction of post-operative hypoxemia, thus achieving better clinical outcome after cardiac surgery. These blocks provide safe and effective postoperative analgesia which facilitates “fast-tracking” in cardiac surgery patients [6].

PECS I/II Block: PECI/II block is a relatively superficial chest wall block which is initially used for breast surgery as radicle mastectomy. PECI/II block can now be used for the implantation of cardiac implantable devices such as automated implantable cardiac defibrillator (AICD) and it has also been used to attain postoperative analgesia after cardiothoracic surgery [26,41].

Technique

PECS I block: With patient in supine position, a 22G Needle is introduced either via mediolateral approach or cephalocaudal approach after identifying pectorals muscle that contains the axillary vessels and nerves from brachial plexus with ultrasound probe. Hydrolocation technique can also be used by identifying hypoechogenicity after local anesthetic is injected to locate the needle tip and confirmatory nerve stimulation responses. Local anesthetic agent is then injected into space between Pectoralis major and Pectoralis minor.

PECS II block: Patient lies in supine position. As stated above, a 22G needle is used and needle tip positioned between pectoralis major and minor and local anesthetic is injected. Then the needle is repositioned inferolaterally into the space between pectoralis minor and Serratus anterior and local anesthetic is then deposited in the plane between pectoralis minor and Serratus anterior. PECS II blocks not only the pectoral nerves but also the intercostobrachial nerve, long thoracic nerve and intercostal nerves T3-T6 [41]. Based on our experience, it is advisable to start with deeper PECS II block and then perform PECS I block as needle is withdrawn. Complications of PECS I and II blocks include intravascular injection, local anesthetic toxicity, and pneumothorax.

Serratus anterior plane block (SAP)

First described by Blanco et al., in 2013. SAP block is technically much easier to perform than the PECS block in general. SAP block has easily identifiable anatomic landmarks and anticipated hemithorax analgesia [27]. Serratus anterior is fan shaped muscle originating from 1st through 9th rib, and runs posteriorly inserting at the medial border of the scapula's ventral surface. It is innervated by the long thoracic nerve (C5-C7) and helps in lifting the arm above 90° [27,42]. Recently published studies have found that both PECS and SAP blocks are equally effective in providing predictable postoperative analgesia and both can be used for postoperative analgesia in cardiac surgery [27,31,43].

The SAP block can be performed in either lateral decubitus position with patient's ipsilateral hand positioned above the head or in supine position which is usually better tolerated, especially in cases with cervical spine instability. With the ultrasound probe in mid-axillary plane, latissimus dorsi is usually first identified, then the serratus anterior muscle is visualized beneath the latissimus dorsi with thoracic dorsal artery separating them. In the axillary plane, the intercostobrachial nerve, long thoracic nerve, thoracodorsal nerve and T3-T9 intercostal branches can also be seen in between the two muscles. A 22G needle can be inserted into the plane between the two muscles at the fifth rib in the mid-axillary line and local anesthesia can then be administered. A multiple dermatomal sensory block from T2-T9 in the mid-clavicular line anteriorly to complete sensory block over the scapula including the axillary block, can be achieved [27]. SAP block can also be used for continuous local anesthetic infusion by inserting a catheter. Complications from SAP block can be intravascular injection, local anesthetic toxicity, and pneumothorax.

Erector spinae block (ESB)

ESB block with or without PECS block attains complete ipsilateral hemithoracic anesthesia with excellent results [43]. The ESB block offers excellent analgesia with precision, safety and easy to do, while reducing the complications from neuraxial techniques [35,43]. ESB block just like the PECS and SAP block can be used as single injection block technique or as continuous infusion via a catheter for postoperative analgesia [43].

Anatomy

Each Thoracic nerve after exiting from the intervertebral foramen divides into ventral and dorsal branches. The dorsal branch after passing through the costotranverse foramen innervates and traverses through erector spinae to reach superficial dorsal surface (group of three muscles namely spinalis, longissimus thoracic and iliocostalis thoracic). The ventral branch then continues as intercostal nerve [35,43].

Technique

With the patient in sitting position, ultrasound probe is placed approximately 3 cm lateral to T5 spine. A 22G block needle is inserted in cephalocaudal orientation advancing until the needle reaching the interfascial plane between rhomboid major and erector spinae. After confirming with hydrolocation technique, local anesthetics can then be injected. By using ESB technique, cutaneous sensory innervations of ipsilateral T2-T8 including axillary and adjoining lateral chest wall and medial upper forearm can be effectively blocked. Just like the PECS block, a continuous catheter infusion can also be used to attain excellent longer postoperative analgesia for sternotomy or thoracotomy pain [43]. The complications from ESB may include local anesthetic toxicity and intravascular injection.

Paravertebral (PVB)

Paravertebral blocks are another type of chest wall block that can be employed for cardiac surgery. These blocks, although originally performed based on landmark technique, have recently been performed under ultrasound guidance, generally by in-plane approach and can be performed around the thoracic and lumbar vertebrae [20,44]. A continuous catheter approach is used in order to provide continuous analgesia for patients [20]. When compared to thoracic epidural analgesia, PVB is associated with similar level of analgesia with less symptoms of urinary retention, hypotension, nausea and vomiting [20,44].

Anatomy

The thoracic paravertebral space is wedge spaced and located on both sides of the vertebral column, with the left being usually greater in size than the right. The base is formed by the posterolateral aspect of the vertebral body, the intervertebral disc, the intervertebral foramen and its contents, while the anterolateral boundary is formed by the parietal pleura [44]. The superior costotransverse ligament extends from the lower border of the transverse process above to the upper border of the transverse process below and forms the posterior wall of the thoracic paravertebral space. The apex of the space is continuous and the intercostal space is lateral to the tips of the transverse processes. The endothoracic fascia is located between the parietal pleura and the superior costotransverse ligament [44].

Technique

Ultrasound guidance is almost always used today for this block. Both an in-plane and out of plane ultrasound techniques can be employed though the in-plane approach is more commonly used. With the patient positioned in the lateral or prone position, a mark is made about 2.5 cm lateral to the spinous processes, indicating the location of the transverse process as well as the site of needle insertion. Local anesthesia is infiltrated subcutaneously in order to facilitate placement of the block needle. The block needle is then advanced with the aim to contact the transverse process. The needle is then walking off the transverse process under the aid of ultrasound and inserted into the paravertebral space, identified as a subtle loss of resistance or “pop”. Local anesthesia can then be administered via slow fractionated administrations [44]. An alternate approach would be performed using an epidural needle instead of a block needle to facilitate the placement of a catheter and a dilute solution of bupivacaine or ropivacaine can be used for the continuous infusion.

Contraindications to perform PVB include infection at the site of needle insertion, empyema, allergy to local anesthetic drugs, and tumor occupying the thoracic paravertebral space are definitive contraindications. Relative contraindications include hypercoagulable disorders, systemic anticoagulation [44]. Care must be taken with regard to patients with chest wall deformities such as kyphoscoliosis and patients with a previous history of thoracotomy as obliteration of the PVB space and possible dural and intrathecal injection and possible scar tissue formation from a previous thoracotomy can affect the quality of the block [44].

Sternal blocks for cardiac surgery

Background

Pain after cardiac surgery is commonly related to the median sternotomy [45]. The pain intensity of sternotomy is significantly higher in the first two postoperative days. Optimizing pain management after cardiac surgery has become increasingly emphasized, especially with the introduction of fast-track discharge protocols requiring early endotracheal extubation [46,47]. Traditionally, intravenous opioid analgesics have been the mainstay of perioperative pain control in cardiac surgery. However, parenteral opioid-based analgesic techniques can be associated with a number of undesirable effects including delay of tracheal extubation, drowsiness, respiratory depression, nausea, vomiting, ileus, and urinary retention to name a few [48]. Non-opioid analgesics, such as acetaminophen, tramadol, dexmedetomidine, pregabalin and nonsteroidal anti-inflammatory drugs (NSAIDs), are commonly used as adjuncts in the perioperative setting. While these drugs are proven to produce opioid-sparing effects [49]. Some of these drugs can lead to issues that complicate the recovery process after cardiac surgery. For example, NSAIDs are associated with increased risk of gastrointestinal bleeding, renal dysfunction, and possibly increased risk of adverse cardiovascular events such as heart attack and stroke [50]. Furthermore, current evidence suggests that poorly treated acute postoperative pain impacts patient well-being and increases the risk of development of chronic pain [51]. Therefore, regional anesthesia techniques that supplement perioperative pain relief are an important adjunct to multimodal analgesic strategies.

Several well established, effective thoracic nerve blocks exist and are used during chest wall surgery for perioperative anesthesia and analgesia. However, most of these techniques cannot block the internal mammary region, so residual pain may still occur there. Parasternal intercostal nerve blocks

(PSINB) and Thoracic transversus muscle plane block (TTMPB) anesthetize the anterior branches of T2-T7 intercostal nerves and can therefore provide analgesia to the internal mammary region. The Thoracic Transversus Plane block is also referred to as the Transversus thoracic muscular plane Block (TTMPB) in some literature. We will use the terms interchangeably here.

The TTMPB block was first described by Ueshima et al. [52]as an adjunct to the PECS II block for breast surgery and as an analgesic block for cardiac surgery. In 2005, McDonald et al. described a parasternal infiltration proven to be effective for pain reduction after median sternotomy [53]. Later, ultrasound-guided parasternal Pecs block was introduced as a supplement to PECS I, PECS II, and Serratus Anterior plane block in breast surgery when the parasternal area is involved [54]. While these blocks involve slightly different techniques, they all target the anterior branches of the intercostal nerves [55]. We will focus on the Parasternal intercostal nerve block (PSB) and the Transverse Thoracic Muscle Plane block (TTMPB) here.

The sternum and manubrium are innervated by the intercostal nerves which are part of the somatic nervous system. These nerves arise from the anterior rami of spinal nerves from segments T1-T11. The first two nerves supply the proximal sternum and manubrium. These nerves supply sensation to the skin and play a role in the contraction of the intercostal muscles. Sternotomy incision is thought to be less painful than a thoracotomy because the manubrium and sternum have fewer nerves [56]. However, postoperative pain for the adult cardiac surgery patient is multi-faceted. Pain is caused by incision, intraoperative tissue retraction and dissection, multiple intravascular cannulations, chest tubes placed during surgery and the multiple invasive procedures that patients undergo as part of their therapeutic regimen [45].

Indications

PSB and TTMPB can be effective for sternal fractures or surgeries at or near the sternum, such as median sternotomy, thymectomy, mediastinoscopy, or pericardial window [57]. These blocks may also be useful for sub-xiphoid incisions. PSB blocks have been studied in both adults and children and proven to be effective [58,59]. The TTMPB block has been studied in adults but no study exists in the pediatric population yet. Both blocks can be used preoperatively, intraoperatively, or postoperatively [60]. These blocks can be combined with other truncal blocks to provide anesthesia and analgesia for other chest wall surgeries such as mastectomy and subcutaneous implantable cardioverter-defibrillator placement [61,62]. Since majority of cardiac surgeries is performed via median sternotomy, this is therefore one field where these blocks may be particularly beneficial for perioperative pain control in cardiac surgery patients.

Technique

There are some important anatomic structures to consider when performing sternal blocks. The transversus thoracic muscle has attachments to the costal cartilages of the second to sixth ribs, as well as attachments to the sternum, and xiphoid process. It functions to depress the costal cartilages during expiration and is innervated by the intercostal nerves [61,62]. This muscle is continuous with the transversus abdominis muscle. The internal mammary vessels are also important structures to consider when placing a sternal block. The internal mammary vessels lie superficial to the transversus thoracis muscle. These vessels are found within 20 mm of the lateral sternal border. The vein is a single vessel that courses medial to the artery and can be found cranial to the level of the second or third rib. Caudal to the third rib, there are usually two veins, one medial and one lateral, flanking the single artery. Even though the block is shallow, since it is located in close proximity to the internal mammary vessels, TTMPB is usually considered with similar precautions as for neuraxial blocks to reduce the risk of bleeding [57].

Transversus thoracic muscular plane block

The TTMPB intends to anesthetize the anterior cutaneous terminal branches of the intercostal nerves that supply the medial and parasternal areas of the chest wall (T2-T7). It can be performed bilaterally using ultrasound guidance and either as a single shot or continuous infusion with a catheter. The technique described below can be used in normal sized adult patients (see Table 2).

Step 1: A linear, high-frequency ultrasound transducer is placed in the parasagittal plan in the midsternal area at the level of the 3rd and 4th ribs.

Step 2: Visualize the ribs, intercostal muscles, pleura, and identify the lung sliding. Each intercostal muscle lies in between the ribs. The sternum is a hyperechoic structure. When the transducer is moved medially to contact the sternum, all muscles and pleural structures will disappear and will be replaced by the hyperechoic image produced by the sternum. From the sternum, slowly slide the transducer laterally until the structures reappear. Keep scanning laterally until a dark, black, linear, hyperechoic structure appears below and deep to the intercostal muscle. This thin band represents the transversus thoracic muscle plane.

Step 3: The internal mammary artery and veins must be visualized and avoided during injection of local anesthetic. Before placing the needle, identify the artery, by scanning the surrounding area. Use of Doppler can help to identify arterial flow. If there is difficulty identifying the veins, and the patient is awake, instruct the patient to take a deep breath and hold it. This will increase intrathoracic pressure and promote venous distention. If the patient is under general anesthesia, a Valsalva maneuver can be performed to distend the veins (hold 30 cm water airway pressure for a few seconds while scanning) [57].

Step 4: Insert the needle in-plane to the transducer in the cephalad to caudad direction. Place the tip of the needle between the intercostal muscle and the transversus thoracic muscle plane between the ribs and above the pleural. The transversus thoracic muscle plane acts as a buffer between the needle and the pleura. Cautious hydrodissection should be used to avoid penetration into the pleura.

Step 5: Aspiration before injection usually confirms that the needle is not in a vessel. After confirming negative aspiration, inject 10–15 mL of local anesthetic in 5 mL increments. Be sure to aspirate between each injection. If local anesthetic spread is observed above the costal cartilages, this indicates the injection was made superficial to the internal intercostal muscle. Local anesthetic spread that is observed deep to the costal cartilages indicates an appropriate injection to achieve the TTMPB block. Focal posterior displacement of the pleura is also observed with transversus plane injection [63].

Parasternal intercostal nerve block

Parasternal intercostal nerve block (PSINB) is intended to anesthetize the anterior branches of the intercostal nerves (see Fig. 4). To perform PSINB, local anesthetic is injected between the pectoralis major muscle (PM) and the external intercostal muscle (EIM) [65]. The anterior branches of the intercostal nerve penetrate through these two muscles to innervate the internal mammary area. Therefore, infiltration of local anesthetic into this area should block to anterior branches of the intercostal nerves (Fig. 5). Some authors feel that the PSINB is technically easier than the TTMPB because the transversus thoracic muscle can be difficult to see on ultrasound if it is small. Expertise with needle placement and handling is also important to perform the TTMPB safely since the pleura and internal mammary artery are located in the immediate vicinity of the plane [66] (see Fig. 6).

Complications

Complications such as hematoma, infection, local anesthetic systemic toxicity (LAST) syndrome, nerve injury, and pneumothorax may occur after a parasternal intercostal nerve or TTMPB. Care should be taken to perform these blocks under sterile technique to avoid infection. While pneumothorax is rare, providers performing these blocks should be prepared to perform needle decompression or insert a chest tube if necessary. LAST is also rare, however, local anesthetic uptake from the intercostal region is high, and providers must be able to recognize symptoms and signs of LAST and provide the appropriate treatment in a timely manner. Using dilute concentrations of local anesthetic and dosing below the maximum allowable should decrease the risk of systemic toxicity. Aspiration before injection to rule out intravascular or intrapleural injection should be done as an attempt to reduce these complications. However, negative aspiration is not a guarantee that complications will not occur. Patient should be monitored for 20–30 minutes after the block has been performed to detect these

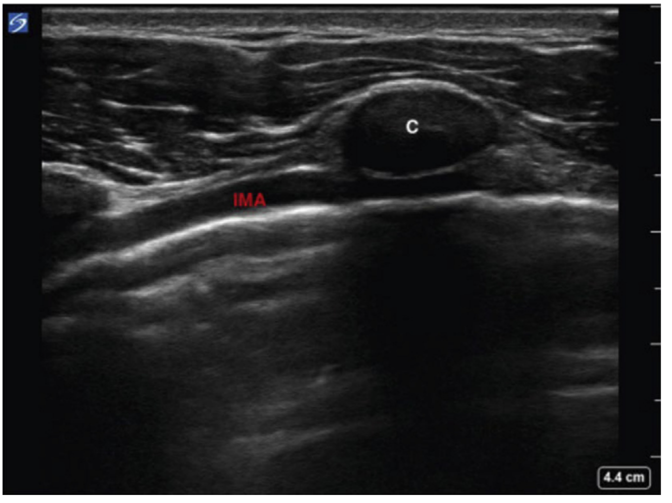

Fig. 4. Long-axis view of the internal mammary artery (IMA) as it travels under the costal cartilage (C) [57].

complications should they occur. Nerve injury with both the PSINB and TTMPB blocks are thought to be low risk as well since they are plane blocks and not directly targeted at single nerves [67].

In one study by Ueshima et al., the authors reported on complications following ultrasound guided TTMPB in a series of 229 consecutive cases. All blocks in this study were administered with a 20-gauge Tuohy needle and high frequency linear probe. Levobupivacaine (15 mL of 0.15% solution) was injected on one side between the transversus thoracic muscle and the intercostal muscle between the 3rd and 4th ribs connecting the sternum. Of the patients included in the study, injection site infections occurred in two patients who had cardiac surgery. No patients developed hematoma or pneumothorax [52]. In a 2019 pilot feasibility study of 19 patients by Fujii et al., [68], 18–90 year old patients undergoing elective cardiac surgery were randomized to the block or standard care control group on admission to the ICU after surgery. Under ultrasound-guidance, the patients in the block group received 20 mL of either 0.3% or 0.5% ropivacaine (based on weight) bilaterally at the target site. All data collection was performed by blinded assessors and blocks were performed by a single anesthesiologist. In each group eight patients received the intervention. There were no adverse block-related events. While this study has a small sample size, the authors believe it provides some preliminary data supporting the safety of the TTMPB block in practice. More trials are needed to further understand the potential complications and their frequency associated with transversus thoracic muscle plane blocks.

The parasternal nerve block has been reported in both pediatric and adult patients undergoing cardiac surgery [58,59]. In a 2011 double-blinded, randomized, controlled trial investigating parasternal intercostal blocks for postoperative analgesia in 30 children undergoing cardiac surgery via median sternotomy, there were no immediate complications reported [59]. In a 2006 double-blinded randomized controlled trial by Barr et al., PSINB using were administered to 88 adults undergoing cardiac surgery [59]. No complications related to the parasternal blocks were reported.

Both TTMPB and PSINB have been proven to be helpful adjuncts in the setting of cardiac surgery. It is well established that the addition of TTMPB to pectoral nerve blocks is beneficial for patients undergoing other chest wall surgeries such as breast surgery [69]. There is no large-scale randomized controlled trial investigating the effects of TTMPB block on postoperative pain control in cardiac surgery patients. However, a large number of case reports exist, and a number of ongoing clinical trials can be found in the literature. In the feasibility study by Fujii et al. [68], the mean pain scores at rest were lower in the block group than in the control group at 12 hours (3.3 vs. 5.6). At 24 hours, the pain scores were similar between groups (4.1 vs 4.1). The mean 24-hour hydromorphone administration was lower in the group received blocks (1.0 mg vs 1.8). The preliminary results of this study showed a high patient

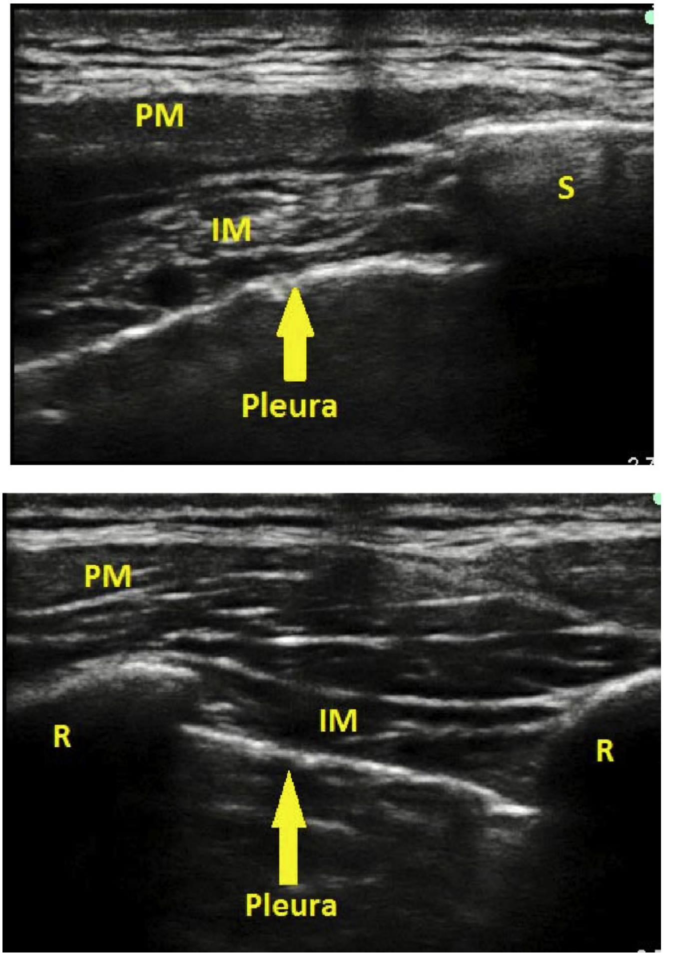

Fig. 5. A) Ultrasound transversal view of the intercostal space. To perform PSINB, a local anesthetic is injected into the plane between the pectoral major muscle and external intercostal muscle. PM pectoral major muscle, IM intercostal muscle, S sternum. B) Ultrasound sagittal view of the intercostal space. R rib.

satisfaction rate and provided some preliminary data on TTMPB block as a method of improving analgesia following surgery and reducing opioid consumption. In 2016, Ueshima et al. presented 2 reports of continuous transversus thoracic muscle plane block for median sternotomy pain [69]. Case 1 was an 82-year-old female with hypertension and diabetes mellitus and severe aortic stenosis who underwent aortic valve replacement. After induction of general anesthesia, bilateral TTMPB blocks were performed by injection of 0.375% levobupivacaine 40 mL in total (20 mL injected into each side) into the fascial plane between the transversus thoracic muscle and the intercostal muscle at between the 4th and 5th connecting at the sternum by under ultrasound-guidance. After the injections, a catheter was inserted in the injection sites bilaterally. The catheters were attached to devices, set to deliver an intermittent bolus of 20 mL (10 mL injected into each side) levobupivacaine 0.1% every hour and 6 mL (3 mL injected into each side) levobupivacaine 0.1% with a lock out time of 30 min for 2 days postoperatively. Case 2 was a 65-year-old male with thymoma who underwent thymectomy. Bilateral TTMPB were performed. The dosage of bilateral TTMPB was the same as in Case 1. According to their report, neither patient complained of perioperative pain and neither required additional analgesic

Fig. 6. High thoracic epidural anesthesia performed at the level T2-T3 [74].

agent. There was no adverse event reported. While more clinical investigations are needed to further understand TTMPB, these cases suggest that this block has the potential to improve perioperative analgesia in patients underwent median sternotomy [70].

PSINB have been proved to improve postoperative pain control and may especially be helpful in patients expected to undergo early tracheal extubation after cardiac surgery [53]. In this 2005 randomized controlled, double-blind study by McDonald et al., The investigators evaluated the effect of PSINB on postoperative analgesia, respiratory function, and extubation times. Twenty patients undergoing cardiac surgery via median sternotomy were enrolled; 17 patients completed the study. A desflurane-based, small dose opioid anesthetic was used during the case. In this study, PSINB block and local anesthetic infiltration of the sternotomy and drain sites was performed by the surgeon prior to sternal wire placement. Patients either received 54 mL of saline placebo or 54 mL 0f 0.25% levobupivacaine with 1:400,000 epinephrine. Pain scores and respiratory function was studied over the next 24 hrs. Patients in the levobupivacaine group consumed significantly less morphine in the first 4 hours after surgery (20.8+/-6.2 mg versus 33.2+/-10.9 mg in the placebo group; $P = 0.013$); they also had better oxygenation at the time of extubation. Four of nine in the placebo group needed rescue pain medication, versus none of eight in the levobupivacaine group ($P = 0.08$). Peak serum levobupivacaine concentrations were below potentially toxic levels in all patients (0.64+/-0.43 μg/mL; range, 0.24–1.64 μg/mL). This study suggests that parasternal block and local anesthetic infiltration of the sternotomy wound and mediastinal tube sites with levobupivacaine can be a useful analgesic adjunct for patients who are expected to undergo early tracheal extubation after cardiac surgery. In the study by Barr et al. [58]. Parasternal intercostal block improved analgesia in postoperative cardiac surgical patients. In this study, the surgeon injected Ropivacaine 0.75% with 5 doses each side (40 mL or 300 mg total) or saline via parasternal intercostal injection before insertion of sternal wires. The patients in this study who received block with ropivacaine also showed better pain scores and reduced opioid consumption in the first 24 hours following surgery compared to the saline group. In the pediatric study by Chaudhary et al. [59]. Patients were randomized and received either 0.5% ropivacaine with 5 doses of 0.5–2.0 mL on each side in the 2nd to 6th parasternal intercostal space with a total dose of ropivacaine below 5 mg/kg, or the same volume of saline before sternal wound closure. The time to extubation was significantly lower in patients who received the parasternal blocks with ropivacaine than in the control group; the mean values were 2.66 hours and 5.31 hours, respectively ($p < 0.001$). The pain scores were also lower in the ropivacaine group compared with the saline group; mean values were 2.20 for the ropivacaine group and 4.83 for the saline group on a scale of 10. The cumulative fentanyl dose requirement over a 24-hour period was higher in the saline group than the ropivacaine group ($p < 0.001$). These studies suggested that parasternal intercostal blocks with appear a simple, safe, and useful technique of supplementation of postoperative analgesia in adult and pediatric patients undergoing cardiac surgery with a median sternotomy.

Neuraxial techniques in cardiac surgery

It is well known that cardiac surgery is associated with significant postoperative morbidity and mortality. In addition to significant stress, cardiac surgery may cause a shift in the myocardial oxygen supply/demand ratio, increased catabolism, and impaired immune function [16]. In an effort to diminish some of these risks, alternative anesthesia techniques in cardiac surgery have become the subject of numerous studies. Although the standard practice remains general anesthesia as the mainstay anesthesia technique for cardiac surgery, the addition of neuraxial techniques has shown promise. Neuraxial anesthesia is a common preference for fast-track anesthesia protocols across the world. Although its use remains highly debated in the setting of cardiac surgery, some anesthesia providers use thoracic epidural anesthesia (TEA) or spinal anesthesia as an adjunct to general anesthesia in this setting [71]. Neuraxial anesthesia techniques as an adjunct to general anesthesia in cardiac surgery has long been hypothesized to reduce some of the risks associated with cardiac surgery by improving postoperative analgesia, attenuating stress response to surgery, improving coronary blood flow, reducing oxygen demand, improved postoperative respiratory function, faster recovery of awareness, and establishment of spontaneous ventilation [72]. The current research focuses on TEA or spinal anesthesia as an adjunct to general anesthesia during coronary artery bypass graft surgery (CABG). A 2005 study by Djaiani et al. showed that regional anesthetic techniques resulted in shorter postoperative ventilation, improved postoperative pulmonary function, reduced incidence of supraventricular arrhythmias, improved postoperative analgesia, and lower rates of myocardial infarction (by up to 50%), as well as, reduced ICU stays and medical cost [71]. However, conflicting data has also been presented [71]. A study in 2011 showed a reduction in short-term or long-term postoperative complications in patients who underwent cardiac surgery with TEA as an adjunct to general anesthesia. However, this reduction was not statistically significant [73].

Thoracic epidural anesthesia

Most TEA studies were performed with Ropivacaine or bupivacaine bolus on the day of surgery between C7 and T3. The duration of the epidural analgesia may vary based on the need for postoperative analgesia, which is one of the benefits of this technique [71]. In the setting of invasive surgery, pain control becomes a significant factor for patient recovery. Epidural analgesia may be used for extended periods of time after surgery to provide pain relief without the side effect profile of other potent analgesics. Patients under TEA following CABG showed lower sedation scores and less reported drowsiness. In addition to pain control, the use of TEA has been shown to improve postoperative respiratory function. Epidural anesthesia could reduce postoperative respiratory failure and lower respiratory tract infections (by up to 50%). These results reflect the shorter postoperative mechanical ventilation time in patients under TEA vs spinal anesthesia and general anesthesia alone [11,71]. Shortened mechanical ventilation time and minimizing the use of intravenous or oral respiratory depressant analgesics significantly reduces patient morbidity and postoperative complications.

Inflammatory responses, mediated by inflammatory cytokine release, is a significant factor in all surgical operations. A reduction in inflammatory response can reduce the potential for renal injury. TEA in combination with epidural clonidine has led to a significant reduction in postoperative renal failure after CABG due to modulation of the sympathetic tone in renal vascular bed [71].

Perioperative cardiac function must be closely monitored in patients undergoing off-pump cardiac surgery. Maintaining significant cardiac perfusion is particularly important in patients undergoing CABG. In addition to a significant reduction in cardiac output and left ventricular contractility, high TEA has been associated with a lower cardiac index, mixed venous oxygen, and a reduced oxygen supply-demand ratio throughout the perioperative period [12,71]. This reduction in coronary perfusion pressure may potentially result in myocardial ischemia. Although TEA has been shown to reduce mean arterial pressure, the use of vasopressors can be used to offset this affect.

TEA technique

Casalino et al. described one technique for TEA in cardiac surgery. “One hour before being taken to the operating room, patients are injected intramuscularly with atropine (10 μg/kg), fentanyl (1 μg/kg), and droperidol (0.35 mg/kg). An epidural 19-gauge catheter is inserted at the level of the T3–T4 intervertebral space and advanced 4 cm in the attempt to reach the T1 vertebral body. A test dose of 2 mL of 2% lidocaine is administered in order to exclude subarachnoid displacement of the catheter. Arterial blood pressure is monitored via a cannula placed in the radial artery. After 2 hours of observation in the waiting area, during which the patient is monitored for the development of neurologic complications, 7 mL/kg of crystalloid solution is given over 20 minutes; then 0.5% bupivacaine (0.15 mg/cm body length) and alfentanil (6 μg/cm body length) are slowly delivered through the epidural catheter. The extent of neural blockage is checked by a pinprick. Patients are then taken to the operating room, where general anesthesia is induced intravenously with alfentanil (6 μg/kg), propofol (1–1.5 mg/kg), and vecuronium (0.1 mg/kg) and maintained with an infusion of propofol (3–5 mg/kg/h) and a bolus dose of vecuronium (0.02 mg/kg) every 20 minutes. Continuous infusion of bupivacaine (0.06 mg/cm body length/h) and alfentanil (3 μg/cm body length/h) is administered through the epidural catheter and continued until 48 hours after the end of the operation. Arterial blood pressure is continuously monitored throughout the procedure. Hypotension is treated with a continuous infusion of noradrenaline at an initial dose of 0.01 μg/kg/min until basal levels are restored. A 300-IU/kg dose of heparin is given immediately before the arterial cannula is inserted into the aorta, and subsequent doses are administered in bolus in order to maintain an activated coagulation time >450 seconds [11,72–74] (Fig. 6).

High spinal anesthesia

Most high spinal anesthesia techniques studied used intrathecal hyperbaric bupivacaine. Although less studied than TEA, high spinal anesthesia has shown to significantly reduce atrial beta-receptor dysfunction and lower serum epinephrine, norepinephrine, and cortisol levels in CABG patients. The effects of this perioperative reduction in stress hormones remain unclear. Spinal anesthesia is also associated with a reduction in mean arterial pressure. These patients were shown to require more vasoconstrictors during preoperative period compared to TEA. However, they showed improved immediate postoperative antihypertensive control [16,71].

Like TEA, spinal anesthesia was found to decrease postoperative analgesic requirements. The administration of spinal anesthesia showed visual analog scale pain scores were significantly lower in CABG patients who had spinal anesthesia with general anesthesia as opposed to general anesthesia alone [12,71]. This improved analgesic affect provides that same pulmonary benefits as discussed with TEAs. However, unlike TEA, spinal anesthesia techniques as an adjunct to general anesthesia in cardiac surgery has not been sufficiently studied with respect to short and long-term cardiac morbidity and shows no difference in intubation times or length of stay [11,12,71].

The Winnipeg technique for spinal anesthesia

The anesthetic technique used for delivering a high or total-spinal anesthetic is outlined as follows (Dr. Trevor W. R. Lee, contributing author, personal communication, July 3, 2007) “Patients are premedicated with oral diazepam (0.1 mg/kg), and peripheral venous and arterial access are obtained in the operating room. Central venous access can be placed pre- or post-induction. Volume repletion and intravenous volume loading is accomplished with 500 mL Pentaspan (Bristol-Myers Squib, New York, NY). The patient is then placed in the lateral decubitus position, and the lumbar spine area is sterilely prepared and draped. A 25- or 27-gauge pencil point spinal need is used to administer the intrathecal block. A dose of 45 mg of 0.75% hyperbaric bupivacaine in combination with 3 μg/kg of preservative-free spinal morphine (maximum total dose 300 μg) is injected into the intrathecal space. The intrathecal injectate volume is thus up to 6.3 mL. The bevel of the spinal needle is facing cephalad during injection.

After intrathecal injection, the patient is immediately placed in the supine position, and the operating room table is placed in less than 5 degrees of Trendelenburg. Steep Trendelenburg positioning is not required with this high dose and volume of intrathecal bupivacaine. Induction of general anesthesia is delayed until a cardiac sympathectomy is achieved. A T1 sensory block or higher can be immediate, but often takes up to 8–12 minutes. During this time, the patient is reassured, and spontaneous ventilation is not inhibited by the spinal until the sensory block is above C5. Small aliquots of intravenous ephedrine (2.5–5.0 mg) and phenylephrine (60–120 μg) are used to maintain the mean arterial pressure above 65 mm Hg. After preoxygenation, once a complete cardiac sympathectomy is achieved, general anesthesia is induced, using intravenous propofol 0.5–1.0 mg/kg and rocuronium 0.6–1.0 mg/kg. Intravenous narcotics can be administered to blunt the stimulation secondary to laryngoscopy, but are not required during maintenance secondary to the total spinal effect. To maintain amnesia and hypnosis, general anesthesia is maintained with 0.5–1.0 MAC end-tidal equivalents of inhaled agent (sevoflurane), with 0.5–1.0 MAC equivalents delivered during cardiopulmonary bypass. After weaning off bypass and post chest closure, the patient is given titrated doses of intravenous narcotics as necessary to achieve a respiratory rate between 15 and 20 breaths per minute. Before chest closure, adjunctive analgesia can be provided for the patient by having the surgeons administer bilateral parasternal blocks, using weight-adjusted maximum doses of 0.25% plain bupivacaine. Acetaminophen (650 mg) per rectum can also be given. Patients are extubated immediately after procedure either in the operating room (OR), and transferred awake to the ICU. Intermittent nurse-administered intravenous morphine followed by regularly dosed oral acetaminophen with codeine is used for postoperative analgesia [16].

Complications and indications

The most widely known and discussed risks of neuraxial anesthesia are epidural hematoma, epidural abscess, and spinal cord infarction. These risks seem to be intuitive due to systemic heparinization which is necessary for open heart surgery. However, recent data has shown minimal a incidence of these complications. The risk of epidural hematoma in cardiac surgery patients has been theorized to occur in about 1 in 857 patients [11,12,71]. Patients with reduced platelets, poor platelet function, reduced coagulablility, or low molecular weight heparin use are at increased risk for hematoma formation. Neuraxial anesthesia is contraindicated in fully anticoagulated patients with a therapeutic INR/PTT [16]. Spinal hematoma has an estimated maximum risk of 1/3600 with spinal anesthesia and 1/1500 with TEA. However, clinic data seem to indicate an even much lower incidence. Risks can be minimalized by avoiding aspirin and other antiplatelet drugs 7–10 days prior to surgery, avoiding blocks in patients with coagulopathy, difficult or traumatic epidural attempts, using midline approach, delaying surgery if bloody tap occurs, removing catheters only after normal hemostasis has been restored postoperatively. Avoidance of long-acting anticoagulants and antiplatelet agents while catheter is in place [71]. Risks of epidural abscess and spinal cord infarction have not been adequately studied in patients with neuraxial anesthesia for cardiac surgery, but the incidence should be assumed to be the same or increased after these procedures. Although pretty rare, direct mechanical injury to spinal cord with puncture needle and neurotoxic reactions to epidural tissue have also been reported [71].

Hypotension is a significant side effect of both TEA and spinal anesthesia. The use of vasopressors during surgery to maintain adequate perfusion pressure is usually required. The use of alpha-agonists in this setting may be associated with the significant reduction in left ventricular contractility discussed previously. This use of vasopressors may also be responsible for the reduction in coronary blood flow in patients undergoing CABG surgery [12,71]. Casalino et al. showed that TEA may cause significant hypotension in women undergoing cardiac surgery. Thus, woman undergoing cardiac surgery with TEA, require close blood pressure monitoring [72].

The majority of studies looking into neuraxial techniques in cardiac surgery has been conducted on low-risk patients. Due to the lack of clinical investigations in high risk patients, such as those with uncontrolled diabetes mellitus, renal failure, poor left ventricular function, atrial fibrillation, chronic obstructive pulmonary disease, and others should not undergo neuraxial anesthesia for cardiac surgery [71].

Neuraxial techniques for cardiac surgery may only be indicated in low-risk patients undergoing CABG. Unfortunately, there has not been sufficient research conducted on cardiac surgery cases other than CABG. However, current evidence suggests that complications associated with neuraxial anesthesia are relatively low if proper precautions are in place. Thus, without contraindication, neuraxial techniques may be implemented at the discretion of the anesthesiologist. The strongest support for the use of neuraxial techniques in cardiac surgery is that of improved analgesia and decreased incidence of postoperative respiratory complication.

Additionally, the choice to add neuraxial techniques in a cardiac surgery must be made on a case-to-case basis. Djaiani et al. concluded that the utilization of neuraxial techniques in patients undergoing CABG could significant decrease postoperative complication and reduce overall postoperative mortality [71]. However, conflicting data has also been reported. Thus, without significant contraindications, the use of neuraxial techniques in cardiac surgery may be used at the discretion of the anesthesiologist and the preference of surgery team.

In summary, cardiac surgery patients may benefit from regional techniques through careful patient selection and proper application of the indicated techniques. This review article systemically discussed the potential applications of regional anesthesia in cardiac surgery. Specifically, we discussed neuraxial techniques, sternal blocks, and chest wall blocks in terms of their indications, technique, complications, and benefits.

Practice points

- Regional anesthesia techniques have been increasingly used in many cardiac surgical procedures, for the purposes of reducing perioperative consumption of opioid agents and enhanced recovery after surgery.
- The most widely known and discussed risks of neuraxial anesthesia are epidural hematoma, epidural abscess, and spinal cord infarction, however, recent data has shown minimal a incidence of these complications.

Research agenda

- The TTMPB block has been studied in adults but no study exists in the pediatric population yet. More trials are needed to further understand the potential complications and their frequency associated with transversus thoracic muscle plane blocks.

References

[1] WHO. Cardiovascular diseases (CVDs). 2018 [cited 2019 Mar 12]. Available from: https://www.who.int/cardiovascular_diseases/en/.
*[2] Mozaffarian D, Benjamin EJ, Go AS, et al. Heart disease and stroke statistics—2016 update [Internet]. Circulation 2016 Jan 26;133(4):e38–360. https://doi.org/10.1161/CIR.0000000000000350. PMID: 26673558.
[3] US Census Bureau. Older Americans month. May 2017 [cited 2019 Mar 12]. Available from: https://www.census.gov/newsroom/facts-for-features/2017/cb17-ff08.html.
[4] D'Agostino RS, Jacobs JP, Badhwar V, et al. The society of thoracic surgeons adult cardiac surgery database: 2018 update on outcomes and quality. Ann Thorac Surg 2018 Jan;105(1):15–23. https://doi.org/10.1016/j.athoracsur.2017.10.035. PMID: 29233331.
*[5] Chakravarthy M. Regional analgesia in cardiothoracic surgery: a changing paradigm toward opioid-free anesthesia? Ann Card Anaesth 2018 Jul-Sep;21(3):225–7. https://doi.org/10.4103/aca.ACA_56_18. PMID: 30052206.
[6] Noss C, Prusinkiewicz C, Nelson G, et al. Enhanced recovery for cardiac surgery. J Cardiothorac Vasc Anesth 2018 Dec;32(6):2760–70. https://doi.org/10.1053/j.jvca.2018.01.045. PMID: 29503121.
[7] Clowes Jr GH, Neville WE, Hopkins A, et al. Factors contributing to success or failure in the use of a pump oxygenator for complete by-pass of the heart and lung, experimental and clinical. Surgery 1954;36(3):557–79. PMID: 13195976.

[8] Chaney MA. Intrathecal and epidural anesthesia and analgesia for cardiac surgery. Anesth Analg 2006;102(1):45–64. PMID: 16368803.
[9] Kowalewski RJ, MacAdams CL, Eagle CJ, et al. Anaesthesia for coronary artery bypass surgery supplemented with subarachnoid bupivacaine and morphine: a report of 18 cases. Can J Anaesth 1994;41(12):1189–95. https://doi.org/10.1007/BF03020660. PMID: 7867115.
[10] Bignami E, Landoni G, Biondi-Zoccai GG, et al. Epidural analgesia improves outcome in cardiac surgery: a meta-analysis of randomized controlled trials. J Cardiothorac Vasc Anesth 2010 Aug;24(4):586–97. https://doi.org/10.1053/j.jvca.2009.09.015. PMID: 20005129.
[11] Chaney MA. Benefits of neuraxial anesthesia in patients undergoing cardiac surgery. J Cardiothorac Vasc Anesth 1997; 11(6):808–9. PMID: 9327328.
*[12] Ho AM, Chung DC, Joynt GM. Neuraxial blockade and hematoma in cardiac surgery: estimating the risk of a rare adverse event that has not (yet) occurred. Chest 2000;117(2):551–5. https://doi.org/10.1378/chest.117.2.551. PMID: 10669702.
[13] Hemmerling TM, Cyr S, Terrasini N. Epidural catheterization in cardiac surgery: the 2012 risk assessment. Ann Card Anaesth 2013;16(3):169–77. https://doi.org/10.4103/0971-9784.114237. PMID: 23816670.
[14] Horlocker TT, Wedel DJ, Rowlingson JC, et al. Regional anesthesia in the patient receiving antithrombotic or thrombolytic therapy: American society of regional anesthesia and pain medicine evidence-based guidelines (Third Edition) 2010;35(1): 64–101. 64–101. PMID: 20052816.
[15] Horlocker TT, Vandermeuelen E, Kopp SL, et al. Regional anesthesia in the patient receiving antithrombotic or thrombolytic therapy: American society of regional anesthesia and pain medicine evidence-based guidelines (Fourth Edition). Reg Anesth Pain Med 2018;43(3):263–309. https://doi.org/10.1097/AAP.0000000000000763. PMID: 29561531.
[16] Lee TW, Grocott HP, Schwinn D, et al. High spinal anesthesia for cardiac surgery: effects on beta-adrenergic receptor function, stress response, and hemodynamics. Anesthesiology 2003 Feb;98(2):499–510. PMID: 12552211.
[17] Kowalewski R, Seal D, Tang T, et al. Neuraxial anesthesia for cardiac surgery: thoracic epidural and high spinal anesthesia - why is it different? HSR Proc Intensive Care Cardiovasc Anesth 2011;3(1):25–8. PMID: 23440039.
[18] D'Ercole F, Arora H, Kumar PA. Paravertebral block for thoracic surgery. J Cardiothorac Vasc Anesth 2018;32(2):915–27. https://doi.org/10.1053/j.jvca.2017.10.003. PMID: 29169795.
*[19] El Shora HA, El Beleehy AA, Abdelwahab AA, et al. Bilateral paravertebral block versus thoracic epidural analgesia for pain control post-cardiac surgery: a randomized controlled trial. Thorac Cardiovasc Surg 2018 Aug 16. https://doi.org/10.1055/s-0038-1668496. PMID: 30114712.
[20] Scarfe AJ, Schuhmann-Hingel S, Duncan JK, et al. Continuous paravertebral block for post-cardiothoracic surgery analgesia: a systematic review and meta-analysis. Continuous paravertebral block for post-cardiothoracic surgery analgesia: a systematic review and meta-analysis. Eur J Cardiothorac Surg 2016 Dec;50(6):1010–8. https://doi.org/10.1093/ejcts/ezw168. PMID: 27242357.
[21] Pintaric TS, Potocnik I, Hadzic A, et al. Comparison of continuous thoracic epidural with paravertebral block on perioperative analgesia and hemodynamic stability in patients having open lung surgery. Reg Anesth Pain Med 2011 May-Jun; 36(3):256–60. https://doi.org/10.1097/AAP.0b013e3182176f42. PMID: 21490523.
[22] Blanco R. The “pecs block”: a novel technique for providing analgesia after breast surgery. Anaesthesia 2011 Sep;66(9): 847–8. https://doi.org/10.1111/j.1365-2044.2011.06838.x. PMID: 21831090.
[23] Blanco R, Fajardo M, Parras Maldonado T. Ultrasound description of Pecs II (modified Pecs I): a novel approach to breast surgery. Rev Esp Anestesiol Reanim 2012;59(9):470–5. https://doi.org/10.1097/AAP.0b013e3182176f42. PMID: 21490523.
[24] Kumar KN, Kalyane RN, Singh NG, et al. Efficacy of bilateral pectoralis nerve block for ultrafast tracking and postoperative pain management in cardiac surgery. Ann Card Anaesth 2018 Jul-Sep;21(3):333–8. https://doi.org/10.4103/aca.ACA_15_18. PMID: 30052231.
[25] Fujiwara A, Komasawa N, Minami T. Pectoral nerves (PECS) and intercostal nerve block for cardiac resynchronization therapy device implantation. SpringerPlus 2014 Aug 5;3:409. https://doi.org/10.1186/2193-1801-3-409. PMID: 25120950.
*[26] Yalamuri S, Klinger RY, Bullock WM, et al. Pectoral fascial (PECS) I and II blocks as rescue analgesia in a patient undergoing minimally invasive cardiac surgery. Reg Anesth Pain Med 2017 Nov/Dec;42(6):764–6. https://doi.org/10.1097/AAP.0000000000000661. PMID: 29016551.
[27] Blanco R, Parras T, McDonnell JG, et al. Serratus plane block: a novel ultrasound-guided thoracic wall nerve block. Anaesthesia 2013 Nov;68(11):1107–13. https://doi.org/10.1111/anae.12344. PMID: 23923989.
[28] Khalil AE, Abdallah NM, Bashandy GM, et al. Ultrasound-guided serratus anterior plane block versus thoracic epidural analgesia for thoracotomy pain. J Cardiothorac Vasc Anesth 2017 Feb;31(1):152–8. https://doi.org/10.1053/j.jvca.2016.08.023. PMID: 27939192.
[29] Hetta DF, Rezk KM. Pectoralis-serratus interfascial plane block vs thoracic paravertebral block for unilateral radical mastectomy with axillary evacuation. J Clin Anesth 2016 Nov;34:91–7. https://doi.org/10.1016/j.jclinane.2016.04.003. PMID: 27687353.
[30] Moll V, Maffeo C, Mitchell M, et al. Association of serratus anterior plane block for minimally invasive direct coronary artery bypass surgery with higher opioid consumption: a retrospective observational study. J Cardiothorac Vasc Anesth 2018 Dec;32(6):2570–7. https://doi.org/10.1053/j.jvca.2018.04.043. PMID: 30037575.
[31] Kaushal B, Chauhan S, Saini K, et al. Comparison of the efficacy of ultrasound-guided serratus anterior plane block, pectoral nerves II block, and intercostal nerve block for the management of postoperative thoracotomy pain after pediatric cardiac surgery. J Cardiothorac Vasc Anesth 2019 Feb;33(2):418–25. https://doi.org/10.1053/j.jvca.2018.08.209. PMID: 30293833.
*[32] Forero M, Adhikary SD, Lopez H, et al. The erector spinae plane block: a novel analgesic technique in thoracic neuropathic pain. Reg Anesth Pain Med 2016 Sep-Oct;41(5):621–7. https://doi.org/10.1097/AAP.0000000000000451. PMID: 27501016.
[33] Adhikary SD, Bernard S, Lopez H, et al. Erector spinae plane block versus retrolaminar block: a magnetic resonance imaging and anatomical study. Reg Anesth Pain Med 2018 Oct;43(7):756–62. https://doi.org/10.1097/AAP.0000000000000798. PMID: 29794943.
[34] Costache I, Pawa A, Abdallah FW. Paravertebral by proxy – time to redefine the paravertebral block [Internet]. Anaesthesia 2018 Oct;73(10):1185–8. https://doi.org/10.1111/anae.14348. PMID: 29858502.

[35] Krishna SN, Chauhan S, Bhoi D, Kaushal B, Hasija S, et al. Bilateral erector spinae plane block for acute post-surgical pain in adult cardiac surgical patients: a randomized controlled trial. J Cardiothorac Vasc Anesth 2019 Feb;33(2):368–75. PMID: 30055991, https://doi.org/10.1053/j.jvca.2018.05.050.
[36] Nagaraja PS, Ragavendran S, Singh NG, et al. Comparison of continuous thoracic epidural analgesia with bilateral erector spinae plane block for perioperative pain management in cardiac surgery. Ann Card Anaesth 2018 Jul-Sep;21(3):323–7. https://doi.org/10.4103/aca.ACA_16_18. PMID: 30052229.
[37] Leyva FM, Mendiola WE, Bonilla AJ, et al. Continuous erector spinae plane (ESP) block for postoperative analgesia after minimally invasive mitral valve surgery. J Cardiothorac Vasc Anesth 2018 Oct;32(5):2271–4. https://doi.org/10.1053/j.jvca.2017.12.020. PMID: 29336964.
[38] Ueshima H, Hiroshi O. Transapical transcatheter aortic valve implantation performed with an erector spinae plane block. J Clin Anesth 2018 May;46:84. https://doi.org/10.1016/j.jclinane.2018.02.001. PMID: 29414628.
[39] Ho AM, Karmakar MK, Ng SK, et al. Local anaesthetic toxicity after bilateral thoracic paravertebral block in patients undergoing coronary artery bypass surgery. Anaesth Intensive Care 2016 Sep;44(5):615–9. PMID: 27608346.
[40] Ueshima H, Otake H. Ultrasound-guided pectoral nerves (PECS) block: complications observed in 498 consecutive cases. J Clin Anesth 2017 Nov;42:46. https://doi.org/10.1016/j.jclinane.2017.08.006. PMID: 28802149.
[41] Bashandy GM, Abbas DN. Pectoral nerves I and II blocks in multimodal analgesia for breast cancer surgery: a randomized clinical trial. Reg Anesth Pain Med 2015 Jan-Feb;40(1):68–74. https://doi.org/10.1097/AAP.0000000000000163. PMID: 25376971.
[42] Berthoud V, Ellouze O, Nguyen M, et al. Serratus anterior plane block for minimal invasive heart surgery. BMC Anesthesiol 2018 Oct 20;18(1):144. https://doi.org/10.1186/s12871-018-0614-5. PMID: 30340525.
[43] Ince I, Ozmen O, Aksoy M, et al. Erector spinae plane block catheter insertion under ultrasound guidance for thoracic surgery : case series of three patients. Eurasian J Med 2018 Oct;50(3):204–6. https://doi.org/10.5152/eurasianjmed.2018.18147. PMID: 30515044.
[44] Karmakar MK. Thoracic paravertebral block. Anesthesiology 2001 Sep;95(3):771–80. PMID: 11575553.
[45] Mueller XM, Tinguely F, Tevaearai HT, et al. Pain location, distribution, and intensity after cardiac surgery. Chest 2000; 118(2). https://doi.org/10.1378/chest.118.2.391. PMID: 10936130.
[46] Li M, Zhang J, Gan TJ, et al. Enhanced recovery after surgery pathway for patients undergoing cardiac surgery: a randomized clinical trial. Eur J Cardiothorac Surg 2018 Sep 1;54(3):491–7. https://doi.org/10.1093/ejcts/ezy100. PMID: 29514224.
*[47] Engelman DT, ben Ali W, Williams JB, et al. Guidelines for perioperative care in cardiac surgery. JAMA Surg May 2019. https://doi.org/10.1001/jamasurg.2019.1153. PMID: 31054241.
[48] White PF, Rawal S, Latham P, et al. Use of a continuous local anesthetic infusion for pain management after median sternotomy. Anesthesiology 2003 Oct;99(4):918–23. PMID: 14508326.
[49] Rafiq S, Steinbrüchel DA, Wanscher MJ, et al. Multimodal analgesia versus traditional opiate based analgesia after cardiac surgery, a randomized controlled trial. J Cardiothorac Surg 2014 Mar 20;9(52). https://doi.org/10.1186/1749-8090-9-52. PMID: 24650125.
[50] Varga Z, Sabzwari SRA, Vargova V. Cardiovascular risk of nonsteroidal anti-inflammatory drugs: an under-recognized public health issue. Cureus 2017;9(4). https://doi.org/10.7759/CUREUS.1144. PMID: 28491485.
[51] Kehlet H, Jensen TS, Woolf CJ. Persistent postsurgical pain: risk factors and prevention. Lancet 2006 May 13;367(9522): 1618–25. https://doi.org/10.1016/S0140-6736(06)68700-X. PMID: 16698416.
[52] Ueshima H, Otake H. Ultrasound-guided transversus thoracic muscle plane block: complication in 299 consecutive cases. J Clin Anesth 2017;41. https://doi.org/10.1016/j.jclinane.2017.03.056. PMID: 28802610.
[53] McDonald SB, Jacobsohn E, Kopacz DJ, et al. Parasternal block and local anesthetic infiltration with levobupivacaine after cardiac surgery with desflurane: the effect on postoperative pain, pulmonary function, and tracheal extubation times. Anesth Analgesia 2005;100(1):25–32. https://doi.org/10.1213/01.ANE.0000139652.84897.BD. PMID: 15616047.
*[54] Piraccini E, Biondi G, Byrne H, et al. Ultrasound Guided Transversus Thoracic Plane block, Parasternal block and fascial planes hydrodissection for internal mammary post thoracotomy pain syndrome. Eur J Pain 2018 Oct;22(9):1673–7. https://doi.org/10.1002/ejp.1249. PMID: 29770535.
[55] del Buono R, Costa F, Agrò FE. Parasternal, pecto-intercostal, pecs, and transverse thoracic muscle plane blocks: a rose by any other name would smell as sweet. Reg Anesth Pain Med 2016 Nov/Dec;41(6):791–2. https://doi.org/10.1097/AAP.0000000000000464. PMID: 27776103.
[56] Ball M, Adigun OO. Anatomy, angle of Louis. StatPearls. Treasure Island (FL). StatPearls Publishing; 2019. PMID: 29083679.
[57] Gray AT. Transversus thoracis muscular plane block. In: Atlas of ultrasound-guided regional anesthesia; 2019. p. 244–8. https://doi.org/10.1016/B978-0-323-50951-0.00056-6. ISBN: 0-323-50951-7 , 0-323-51209-7.
[58] Barr AM, Tutungi E, Almeida AA. Parasternal intercostal block with ropivacaine for pain management after cardiac surgery: a double-blind, randomized, controlled trial. J Cardiothorac Vasc Anesth 2007;21(4). https://doi.org/10.1053/j.jvca.2006.09.003. PMID: 17678782.
[59] Chaudhary V, Chauhan S, Choudhury M, et al. Parasternal intercostal block with ropivacaine for postoperative analgesia in pediatric patients undergoing cardiac surgery: a double-blind, randomized, controlled study. J Cardiothorac Vasc Anesth 2012;26(3). https://doi.org/10.1053/j.jvca.2011.10.012. PMID: 22176767.
[60] Ziyaeifard M, Azarfarin R, Golzari SE. A review of current analgesic techniques in cardiac surgery. Is epidural worth it? J Cardiovasc Thorac Res 2014;6(3). https://doi.org/10.15171/jcvtr.2014.001. PMID: 25320659.
[61] Kulhari S, Bharti N, Bala I, et al. Efficacy of pectoral nerve block versus thoracic paravertebral block for postoperative analgesia after radical mastectomy: a randomized controlled trial. Br J Anaesth 2016;117(3). https://doi.org/10.1093/bja/aew223. PMID: 27543533.
[62] Bhatt HV, Hernandez N, Shariat A. Successful use of serratus and transversus thoracic plane blocks for subcutaneous implantable cardioverter-defibrillator placement. J Cardiothorac Vasc Anesth 2018 Feb;32(1):e22–3. https://doi.org/10.1053/j.jvca.2017.09.019. PMID: 29217249.
[63] Murata H, Hida K, Hara T. Transverse thoracic muscle plane block: tricks and tips to accomplish the block. Reg Anesth Pain Med 2016;41(3). https://doi.org/10.1097/AAP.0000000000000374. PMID: 27093277.

[64] Mittnacht AJC, Shariat A, Weiner MM, et al. Regional techniques for cardiac and cardiac-related procedures. J Cardiothorac Vasc Anesth 2019 Feb;33(2):532–46. https://doi.org/10.1053/j.jvca.2018.09.017. PMID: 30529177.
*[65] Ueshima H, Otake H. Similarities between parasternal intercostal nerve block and subpectoral interfascial plane block. J Anesth 2017 Jun;31(3):476. https://doi.org/10.1007/s00540-016-2302-2. Epub 2017 Jan 9. PMID: 28070652.
[66] Ohgoshi Y, Ino K, Matsukawa M. Ultrasound-guided parasternal intercostal nerve block. J Anesth 2016 Oct;30(5):916. https://doi.org/10.1007/s00540-016-2202-5. PMID: 27325411.
[67] Baxter CS, Fitzgerald BM. Intercostal nerve block. StatPearls Publishing; 2019 Mar 9. PMID: 29489198.
[68] Fujii S, Roche M, Jones PM, et al. Transversus thoracis muscle plane block in cardiac surgery: a pilot feasibility study. Reg Anesth Pain Med 2019 May;44(5):556–60. https://doi.org/10.1136/rapm-2018-100178. PMID: 30902911.
[69] Ueshima H, Otake H. Addition of transversus thoracic muscle plane block to pectoral nerves block provides more effective perioperative pain relief than pectoral nerves block alone for breast cancer surgery. Br J Anaesth 2017 Mar 1;118(3): 439–43. https://doi.org/10.1093/bja/aew449. PMID: 28203723.
[70] Ueshima H, Otake H. Continuous transversus thoracic muscle plane block is effective for the median sternotomy. J Clin Anesth 2017 Feb;37:174. https://doi.org/10.1016/j.jclinane.2016.12.013. PMID: 28235519.
[71] Djaiani G, Fedorko L, Beattie WS. Regional anesthesia in cardiac surgery: a friend or a foe? Semin Cardiothorac Vasc Anesth 2005 Mar;9(1):87–104. https://doi.org/10.1177/108925320500900109. PMID: 15735847.
[72] Casalino S, Mangia F, Stelian E, et al. High thoracic epidural anesthesia in cardiac surgery: risk factors for arterial hypotension. Tex Heart Inst J 2006;33(2):148–53. PMID: 16878616.
*[73] Svircevic V, van Dijk D, Nierich AP, et al. Meta-analysis of thoracic epidural anesthesia versus general anesthesia for cardiac surgery. Anesthesiology 2011 Feb;114(2):271–82. https://doi.org/10.1097/ALN.0b013e318201d300. PMID: 21239975.
[74] Hemmerling TM, Romano G, Terrasini N, et al. Anesthesia for off-pump coronary artery bypass surgery. Ann Card Anaesth 2013 Jan-Mar;16(1):28–39. https://doi.org/10.4103/0971-9784.105367. PMID: 23287083.